IPEP 500

Non-Confidential Report

0	Feb 26, 2021	Issued for Use	Karen Friedrich	Elizabeth Siemens	Vince Wallwork
REV	**Date**	**Document Status**	**Author**	**Author**	**Approver**

Canadian Natural

EXECUTIVE SUMMARY

The In Pit Extraction Process (IPEP) was first conceived as a way to significantly reduce storage of Non-Segregating Tailings (NST) in tailings ponds, handling the solids only once, while also reducing the associated cost, environmental impact, and liabilities associated with them.

IPEP is innovative in four ways:

1. The sequence of equipment and the use of process aids to separate bitumen from sand and clays;
2. The process yields dry, stackable tailings;
3. The final process plant is modular so that it can be relocated, which allows for maximum flexibility in mine development; and
4. Reduction in transportation of ore, slurry, and tailings, reducing both diesel and electric energy usage.

The concept was first tested in 2017 with a 100 tonne per hour (t/h) pilot at Canadian Natural's Horizon site, followed by the full-scale IPEP 500 (t/h) pilot. The pilot was built and operated at Horizon, and operations and optimization work (Phases) took place between May 2018 and February 2020.

This is the final report for IPEP 500, detailing the pilot's overall execution, including but not limited to earlier development work, IPEP 500 pilot operations and process optimization, data analysis for the final pilot configuration (Phase 3/3B), discussion of results, and recommendations.

The IPEP 500 pilot did meet the target ore throughput of 375 t/h for short durations, however the average throughput was in the range of 300-325 t/h. The average pilot performance in terms of Key Performance Indicators (KPIs) are as follows:

KPI	Phase 3B Target	Final Phase 3/3B Results
Ore Throughput (t/h)	375	300 - 325
Bitumen Recovery (%)	≥ 92	90.7
Froth Quality (wt% bitumen)	≥ 55	42.3
Froth Quality (wt% solids)	< 12	7.29
Tailings Solids (wt% solids)	≥ 86	75 - 80

IPEP 500 was named as it was initially designed to process 500 t/h of ore. However, the belt filter installed in Phase 3 (due to availability) was not able to process more than 375 t/h of plant feed. Though the rest of the plant was capable of 750 t/h of throughput, the feed target was lowered to 375 t/h and only half the material washer screws were utilized.

Overall the pilot was successful in demonstrating the feasibility of the IPEP concept. Though the average KPI results were lower than targets, opportunities for process optimizations have been identified that will improve KPIs and plant reliability.

The pilot campaign was prematurely suspended in early March 2020 as part of the company's initiatives to mitigate the dual impacts of the global pandemic and change in oil price. As such, there are process optimization components in the final Phase 3B configuration that did not see sufficient run-time to evaluate their performance and impact on the KPIs; further pilot work is recommended to enable quantitative assessments on same.

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1 TECHNICAL TERMINOLOGY AND DEFINITIONS

Acronym	Description
AER	Alberta Energy Regulator
Alum	Aluminum sulfate solution
ARO	Asset Retirement Obligation
bbl	Barrel
BFD	Block Flow Diagram
BMH	Bulk Mineral Handling
B/MS	Bitumen to Mineral Solids Ratio
BP	Bitumen Production
COSIA	Canadian Oil Sands Innovation Alliance
DDA	Designated Disposal Area
ESG	Environmental, Social, Governance
ETF	External Tailings Facility (e.g. DDA1)
FA	Fall Average Grade Ore
FFT	Fluid Fine Tailings
FTC	Flotation Cell
GHG	Greenhouse Gas
HMB	Heat and Material Balance
HPW	Hot Process Water
HVBF	Horizontal Vacuum Belt Filter
IPEP	In Pit Extraction Process
IPEP 100	Name of the project that designed, built and modified the 100 t/h pilot plant which was the first IPEP pilot plant
IPEP 500	Name of the project that designed, built and modified the 500 t/h pilot plant
KPI	Key Performance Indicator
LRP	Long Range Plan
NST	Non-Segregating Tailings
O/F	Overflow
OPP	Ore Preparation Plant
OS	Oversized
PFD	Process Flow Diagram
PSC	Primary Separation Cell
PSD	Particle Size Distribution
PSV	Pressure Safety Valve
Q	Quarter
RW	Recycle Water
ROM	Run of Mine
SDP	Surface Drainage Pond

Acronym	Description
SFR	Sand to Fines Ratio
SG	Specific Gravity
SH	Summer High Grade Ore
SI	International System (of Units)
U/F	Underflow
VFD	Variable Frequency Drive
WL	Winter Low Grade Ore
WPW	Warm Process Water

The project uses the international system of units (SI) wherever practical, generally with the exception of pipe sizing.

Unit	Description
cfm	Cubic feet per minute
h	Hours
hp	Horsepower
km	Kilometers
kV	Kilovolt
m	Meters
m^3	Cubic Meters
mm	Millimeters
s	Seconds
t	Tonnes
μm	micrometer
”	Inches
%vol	% by Volume
%wt	% by Weight

2 INTRODUCTION

Canadian Natural has developed the In Pit Extraction Process (IPEP), as an innovative alternative to conventional oil sands slurry preparation, bitumen extraction, and tailings handling.

2.1 Background

Traditionally, ore is mined in pit and transported by diesel-powered haul trucks to an Ore Preparation Plant (OPP) located between 1 to 5 kilometers from the mine. The ore is then crushed and blended with water to create a slurry of bitumen, water, sand, and clay. The slurry is hydro-transported by pipeline several more kilometers to a central Extraction plant for separation and processing to produce Froth.

Froth is further upgraded to reduce the water and solids content in the Froth Treatment plant. Tailings treatments vary from company to company. At Horizon, the tailings are processed in cyclones and thickeners to produce a non-segregating tailings (NST) product that is deposited on the beach of the tailings facility. All tailings storage facilities are known as dedicated disposal areas (DDAs). With the exception of DDA1 (which is also known as the External Tailings Facility [ETF]), the DDAs are formed from the mined-out pits. Significant efforts must be made to ensure the DDAs have sufficient area and dyke structure to hold the fluid material. Within the DDA, the tailings will separate into re-usable process water on top, fines and water mixture called fluid fine tailings (FFT) and course material that settles on beach or to the bottom of the pond. In addition, much of the FFT in the ETF/DDA must be further processed to capture fines and clean the water so that it can be recycled to the plant.

2.2 IPEP's Innovation

The In Pit Extraction Process (IPEP) was first proposed as a way to significantly reduce storage of fluid in tailings ponds, handling the solids only once while also reducing the associated cost, environmental impact, and liabilities. It was also intended to reduce the distance the waste material is transported, resulting in less energy and therefore less greenhouse gas (GHG) emissions.

The concept was first tested in 2017 with a 100 tonne per hour (t/h) pilot at the Horizon site. Building on the initial pilot, it was realized that the IPEP concept could have a much greater potential reach. The innovation lies in the modularization and mobility of the equipment, and in how this equipment, combined with process aids, are utilized to separate bitumen from the sand and clays to yield dry, stackable tailings while reducing GHG emissions.

IPEP is innovative in four ways:

- The sequence of equipment and the use of process aids to separate bitumen from sand and clays;
- The process yields dry, stackable tailings;
- All equipment is designed so that it can be relocated as a module, which allows for maximum flexibility in Mine development; and
- Significant reduction in transportation of ore, slurry, and tailings, reducing both diesel and electric energy usage as well as GHG emissions.

IPEP uses equipment of a type and size that are commercially available and currently used in the mining sector or other industries. This was true for the 100 t/h scale pilot that Canadian Natural had proven, and it is true for the current larger scale of 500 t/h. There is a significant reduction in capital cost with mobile equipment compared to the high sustaining capital cost of relocating and constructing a traditional OPP. The Canadian Natural Horizon, Muskeg River, and Jackpine Mines currently have a total of eight OPP trains.

With IPEP, ore is transported from the Mine face to the IPEP Extraction facility, located within the same pit, reducing the hauling distance and associated diesel requirements significantly. The ore is crushed and mixed with hot process water (HPW) and the resulting slurry is then fed to the washer screws. The IPEP washer screws separate the bitumen, water, sand, and clays through mechanical means. The sand and clays are dewatered to a stackable state and returned to the mined out area of the pit. Only the bitumen froth is transported to the main fixed plant location.

IPEP's reduction in GHG emissions is mainly due to the reduction in hauling and pumping distances for waste material. By locating the IPEP units next to the Mine pit, the ore hauling distance is shortened, which subsequently reduces the diesel requirements and emissions of the haul trucks. Since the ore is then processed at the IPEP facility, instead of pumping the slurry with multiple large pumps several kilometers the Extraction plant, electrical energy consumption is reduced. Similarly, the tailings side of IPEP also conserves energy compared to the existing process. Since the IPEP tailings are drier than the existing process, the total mass and volume of tailings is reduced (same solids moved but with less water content). The IPEP tailings can thus be conveyed the shorter distance back to the Mine pit instead of being pumped. Additionally the water handling systems at the DDA are substantially reduced.

2.3 The IPEP Projects

To-date, the following research and development work has been carried out:

- IPEP 100 pilot work and bench tests (2017)
    - Preliminary technology screening and proof of concept
- IPEP 500 pilot work (2018-2020)
    - Large scale pilot plant operation
    - Additional technology screening

Based on the positive results of the 100 t/h pilot (see Section 4), a larger 500 t/h pilot was designed, built, and operated from 2018 to 2020 to refine the process, demonstrate the ability to meet the key performance indicators (KPIs), and obtain operating data for inputs to a commercial design. This is an essential step in determining whether IPEP is viable on a commercial level.

3 Technology Description

The IPEP process can be broken down into three main steps - Crushing & Conditioning, Bitumen Flotation, and Tailings Dewatering. There are two main input streams (Ore and Hot Process Water) and three output streams (Froth, Stackable Tailings, and Water). Figure 1 shows an overview of the general process. Recycle streams and minor inputs such as polymer addition or gland water are not shown.

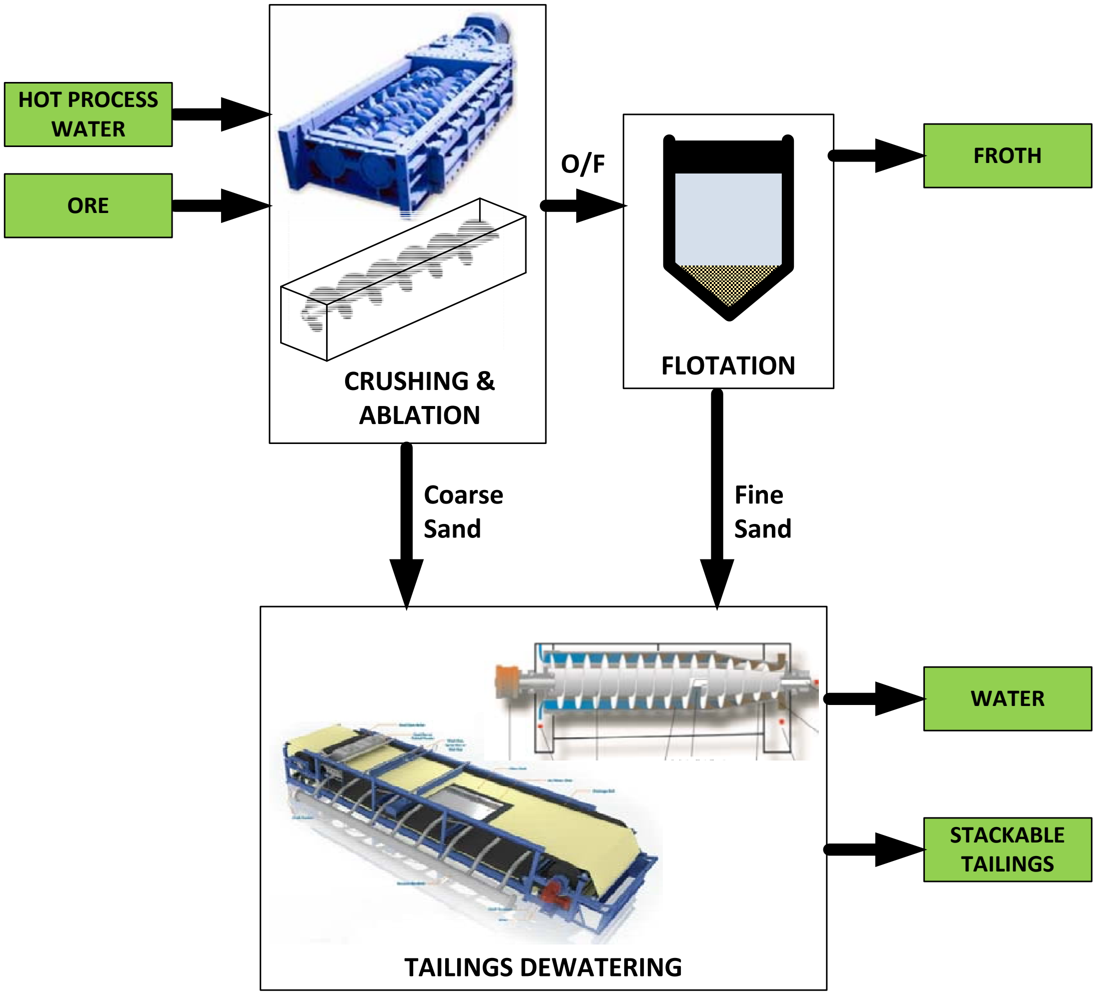


Figure 1: In Pit Extraction Process (simplified)

3.1 Crushing & Ablation

Within the IPEP pilot plant, ore is fed via conveyor to a set of crushers to reduce the ore size down to 2”. The crushed ore is combined with hot water in a pumpbox and the slurry is pumped to a set of washer screws where more hot process water and recycle water are added. The mechanical agitation of the washer screws helps to break up lumps of ore and liberate bitumen. The material leaving the screws is separated into two streams a) a bitumen-rich stream (bitumen, water and fine solids) overflow (O/F) which is sent to the flotation steps, and b) coarse slurry underflow (U/F), which are sent to the tailings dewatering step.

3.2 Flotation

The bitumen-rich stream is further processed through several stages of flotation, where bitumen attaches to air bubbles to form froth. As the froth is less dense than the remaining fine solids and water, the froth floats to the surface of the flotation cells and the O/F is collected in another tank. The collected froth is delivered via pipeline further refining via the existing Froth Treatment plant, the same as it would after the Extraction step in the existing main plant. The flotation circuit U/F contains mainly water and fine solids, and is sent to Tailings for dewatering.

3.3 Tailings

The coarse slurry U/F from the washer screws consists mainly of coarse solids (including rocks) and water. Tailings from the flotation circuit contain mainly fine solids (sand and clays) and water. The tailings streams are treated through different technologies to separate and recover most of the water, and produce stackable tailings that are transported by conveyor to the disposal area. Polymers and other chemicals are added in this tailings step to assist with the dewatering process. Recovered water is recycled within the process.

4 Development Work

IPEP was initially conceived as a black box that could accomplish the processing needs of oil sands in a fashion that would enable a Mine plan designed around minimizing the transport of material. This is different from current Mine plans that are largely driven by the fluid tailings containment needs, in conjunction with the current processing plants. The IPEP concept needed to be modular, easily relocatable and suitable for operation near the Mine face, such that it could be continuously relocated to keep pace with the Mine face advancement, thereby maintaining the short haul distances. This would minimize the material transport requirements and enable the desired Mine plan. IPEP would need to make “dry” tailings product that could be backfilled into the Mine and rapidly reclaimed compared to the current large DDA concept employed with slurry tailings. This would also enable the tailings placement to keep pace with the advancing Mine face and minimize material transport at the same time, reducing the cost of constructing the dams and fluid handling equipment that a DDA requires.

Canadian Natural’s IPEP process development started in 2016 with an assessment of different oil sands extraction technologies at various technology readiness levels. The process design objective was to develop a technology with the following features:

- Producing dry stackable tailings;
- Bitumen recovery and froth quality similar to Horizon Extraction plant;
- Modular and relocatable;
- Reduced number of trucks and shovels; and
- Reduced GHG emissions.

Once the high-level requirements of the IPEP process were established, development began for the process and equipment to accomplish the processing of the oil sands. The approach taken was a departure from the usual process engineering methodology used in oil sands, which typically starts with the process requirements, mass balance and process flows sketched out. The process design then follows, with fitting of equipment and vessel designs to accomplish the process. IPEP development followed a mineral processing design approach. First options were identified for equipment that is existing, available, and where possible, widely used in similar processing applications of other industries. Those pieces with practical application in the type of process operations IPEP required were trialed in the IPEP 100 pilot. The equipment’s capability was evaluated with oil sand materials and processing conditions to determine their capabilities.

Different technologies, including non-aqueous technologies, the Gulf/RioTinto oil sands extraction process, the Alberta Taciuk process (ATP), the low energy extraction process, etc. were evaluated over a series of brain storming sessions and literature reviews from different sources, including Canada’s Oil Sands Innovation Alliance (COSIA) database.

Process components were selected for their compatibility with IPEP processing goals and availability at a commercial scale. The initial flow sheet consisted of a crusher, three washer screws (for ore digestion, conditioning and classification of the solids and primary recovery of bitumen in the feed slurry), a flume for froth separation, and a dewatering screen for final dewatering of the tailings.

After selecting and procuring several readily available pieces of relevant equipment, a 100 t/h IPEP pilot was constructed to test the process. The flowsheet for IPEP 100 Generation 1 is shown in Figure 2.

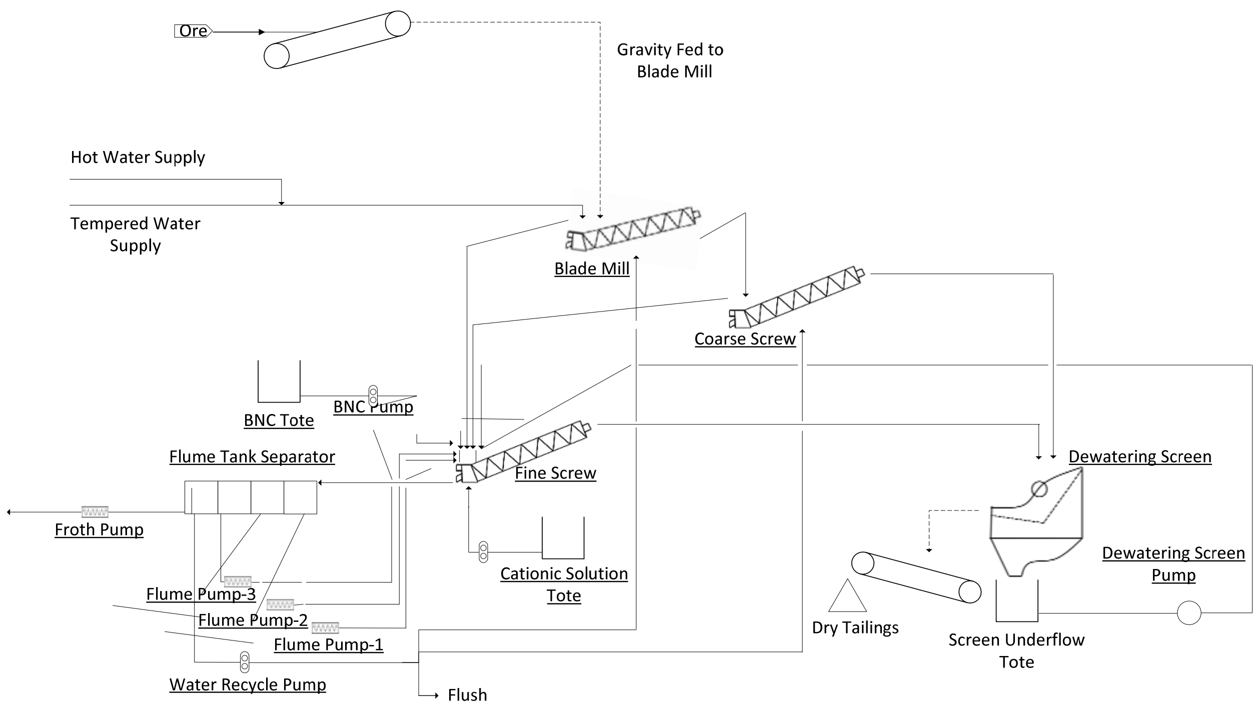


Figure 2: IPEP 100 generation 1 flowsheet

The first stage of the process concept is sizing the ore to less than 2”. This step quickly reduces the lump size to enable rapid ablation of the ore. Ore lump breakdown is a function of time and temperature as the heat of the hot process water penetrates the ore lumps, softening the bitumen that binds the lump together. The time required increases exponentially with the size of the lump, so starting with a small lump size is important for a short-duration ore ablation step.

A series of washer screws were employed to digest and perform initial classification of the ore solids. The screws are a proven technology for washing clays from rock in the aggregate and mineral processing industries. Unlike a slurry line, where much of the energy is used to keep the slurry suspended, washer screws employ concentrated mechanical energy on the lumps that settle to be the bottom of the machine. Only a small portion of the oil sand ore is in the form of lumps, so focusing mechanical digestion on this fraction and removing the digested slurry portion right away improves the energy usage and associated equipment wear and maintenance costs.

Observations with the IPEP 100 Generation 1 flowsheet include good digestion and liberation in the blade mill and coarse washer screw, however dewatering on the screen achieved lower dryness than required. Some of the challenges were polymer addition in the fine screw suppressed recovery, the fine screw had difficulty transporting the sand fraction to the screen, and the flume style flotation experienced solids handling limitations.

IPEP 100 went through several changes (Generations) to test other configurations and equipment.

With the fifth and final IPEP 100 generation, the pilot achieved stable runs on low, medium and high-grade ore at a 50 t/h feed rate. The process was limited to 50 t/h primarily due to the capacity limits of some unit operations such as washer screws and dewatering screens. However, recoveries as high as 97% were achieved for high-grade ore as shown in Figure 3.

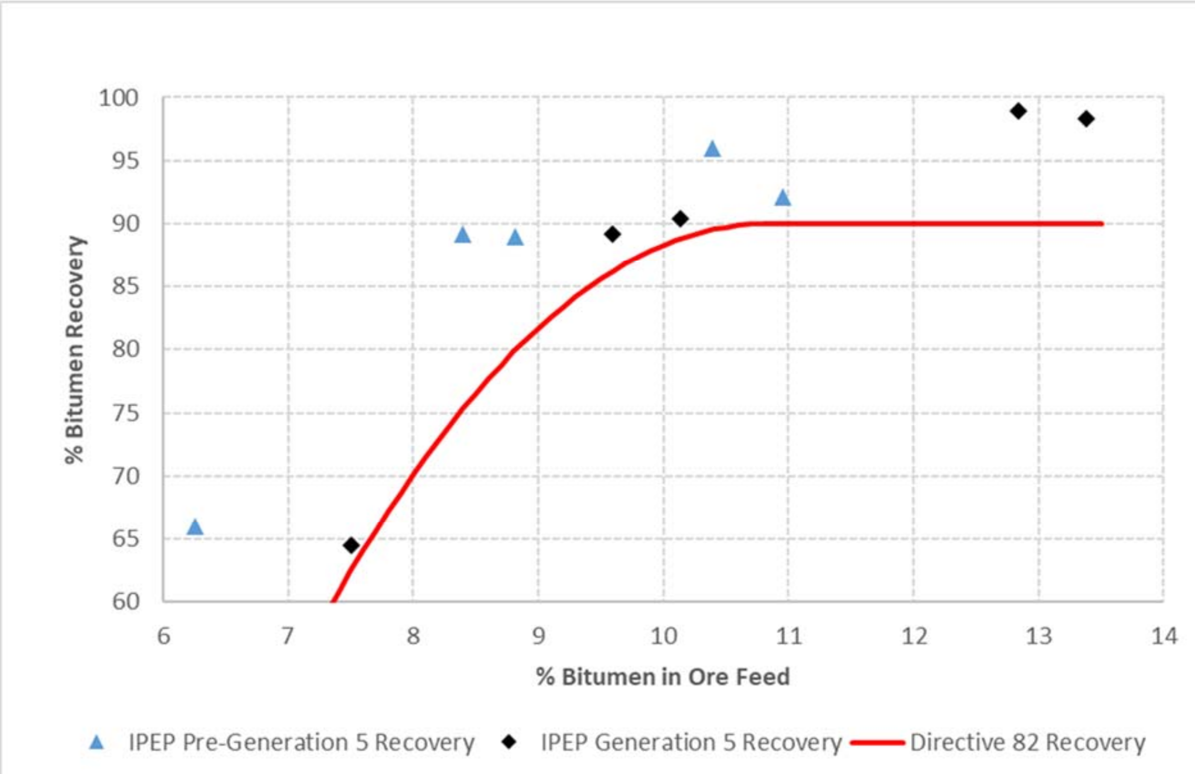


Figure 3: IPEP 100 Generation 5 recovery profile

The fifth generation also resulted in acceptable tailings solids content for tailings streams (i.e. centrifuge cake and dewatering screen tails) for a range of low to high-grade ores as shown in Table 1.

Table 1: IPEP 100 Generation 5 performance

	1-Oct	14-Oct	15-Oct	5-Oct	10-Oct
wt% Bitumen in Ore Feed	7.5	9.6	10. 2	12.9	13.4
wt% Solids in Cake Tailings	76.3	75.2	76.5	69.2	65.5
% Solids in Screen Tailings	82.9	82.6	86.7	84.3	82.9

The outcome of the IPEP 100 program was pilot verification and proof of concept of the process and equipment, with sufficient confidence to proceed to what was envisioned as a full-scale pilot operation. The IPEP 500 (500 t/h) scale flow sheet was developed based on the IPEP 100 development. This flow sheet would become the basis for further development and refinement in the IPEP 500 program.

5 IPEP 500 Project Goals

The initial overall objective of IPEP 500 was to demonstrate commercial feasibility by achieving continuous 24 h all-season operation at the target ore feed rate. The pilot will provide operating data as input for a commercial IPEP design criteria.

The original key performance indicators (KPIs) were modified slightly over the course of IPEP 500's development, as shown in Table 2. The following sections discuss the reasons for KPI modification.

Table 2: IPEP 500 KPIs (Original and Current)

KPI	Original	Current
Ore Throughput (t/h)	500	375*
Bitumen Recovery (%)	≥90	≥ 92
Froth Quality (wt% bitumen)	≥60	≥ 55
Froth Quality (wt% solids)		< 12
Tailings Solids (wt% solids)	Dry, stackable tailings	≥ 86

* Limited by belt filter capacity. Only one train of washer screws in use.

GHG reductions and bitumen production cost reductions are overall goals of the commercial design, which incorporates further infrastructure, operational, and location planning assessments to appropriately quantify IPEP's impacts on these performance factors. Though not a direct objective of IPEP 500, pilot data including power requirements were used in forecasting these KPIs for a commercial implementation of IPEP.

5.1 Ore Throughput

The original IPEP 500 process was designed to operate with an ore feed rate of 500 t/h. The belt filter that was added in June 2019 was the largest available size with a relatively short lead time, however with initial testing it was found that the belt filter was not able to handle the solids from the full 500 t/h feed rate. The decision was made to run only one train of washer screws, reducing the overall plant throughput to 375 t/h. This change proved beneficial by demonstrating that the selected screws are capable of a higher throughput than originally thought (375 t/h vs 250 t/h).

5.2 Bitumen Recovery

Bitumen recovery is grade and fines dependent and set by Directive 082 from the Alberta Energy Regulator (AER). For ore with over 11 wt% bitumen, recovery (OPP + Extraction + Froth Treatment) must meet or exceed 90 wt%. Below 11 wt% bitumen, recovery requirements are given by Equation 1 where x represents the wt% bitumen:

$$\text{Recovery} = -202.7 + 54.1(x) - 2.5(x^2) \qquad \text{Equation 1}$$

For simplicity, the IPEP 500 recovery target was set to match the average recovery of the main plant at Horizon.

5.3 Froth Quality

Froth quality is determined by both the bitumen and solids content in the froth. As the froth produced from the commercial IPEPs is intended to be further upgraded in the existing Horizon Froth Treatment plant it is important that the froth meets the requirements of this plant. For bitumen content, 60 wt% bitumen was deemed a stretch target and reduced to 55 wt% bitumen to match the existing froth quality target at Horizon. For solids content, a target of less than 12 wt% was added, again matching the existing froth quality target at Horizon. Note that froth temperature is also an important parameter for the Froth Treatment plant, but was not an IPEP 500 KPI.

5.4 Tailings Solids

One of the primary objectives of IPEP is to return the separated solids back to the mine pit for disposal, without the need for containment structures. Determining the required solids content to produce dry, stackable tailings was part of the test plan. Sample collection and testing enabled establishing the minimum target at 86 wt% solids to achieve the goal of dry stackable tailings.

6 IPEP 500 Pilot Phases

Based on the positive results of IPEP 100, a larger 500 t/h pilot (IPEP 500) was designed, built, and operated from Q2 2018 through Q1 2020. The pilot was at Horizon and was tied into existing systems, including water and utilities supply. Bitumen froth produced at IPEP was sent via hydrotransport back to the main Extraction plant.

Table 3: IPEP 500 Equipment by Phase is a summary of the overall process configuration and equipment used in each operating Phase. A descriptive overview of each Phase is also provided in the following sections.

Table 3: IPEP 500 Equipment by Phase

	Phase 1 May - Sept 2018	**Phase 2** Nov 2018 – May2019	**Phase 3** June - Aug 2019	**Phase 3B** Nov 2019 - Feb 2020
Feed Conveyors	Rental	Rental	Rental	Owned
Crushers	Rental	Cone Crusher	Cone Crusher	2 stage Sizers
Screws	2 x 2 Washer Screws	2 x 2 Washer Screws	2 x 2 Washer Screws	2 Washer Screws
Flotation	3 stages of Flotation	3 stages of Flotation	3 stages of Flotation	3 stages of Flotation
Screens	Vibrating Screens (2 in parallel)	Vibrating Screens (2 in parallel)	Vibrating Screens (2 in parallel)	None
Centrifuges	Lynx 1000 (4 in parallel)	Lynx 1000 (4 in parallel)	Lynx 1000 (4 in parallel)	Lynx 1000 (2 in parallel)
Cyclones	n/a	n/a	4 x 12”	4 x 12”
Belt Filter	n/a	Test scale unit	25m x 3m unit	25m x 3m unit
Thickener	n/a	n/a	n/a	6m Thickener
Tailings Conveyors	Rentals	Rentals	Rentals	Owned

Please refer to Section 7 for detailed accounts of the individual unit operations, including issues encountered, optimizations, and lessons learned.

Photos of the IPEP 500 pilot and equipment can be found in Appendix D – IPEP 500 Photos (note reference photos are numbered D.#).

6.1 Phase 1

Phase 1 included the engineering design, construction, and commissioning of the initial IPEP 500 plant.

The plant included rental conveyors and crushers that fed parallel trains each with two washer screws (see photos D.6 and D.7). Coarse sand and rocks that were separated with the screws was then dewatered on a pair of screens (see photo D.8) and discharged to tailings conveyors. Froth from the screws overflowed to the flotation circuit to concentrate the bitumen. The remaining tailings material was sent to up to four centrifuges (see photo D.16) to concentrate the tailings material. The centrifuge tailings were combined with the screen tailings onto tailings conveyors. Centrate from the centrifuges was re-used as recycle water within the plant.

Plant commissioning and start-up was performed in May 2018, and operated as Phase 1 from May 2018 to September 2018.

An overview of the process in Phase 1 is shown in Figure 4.

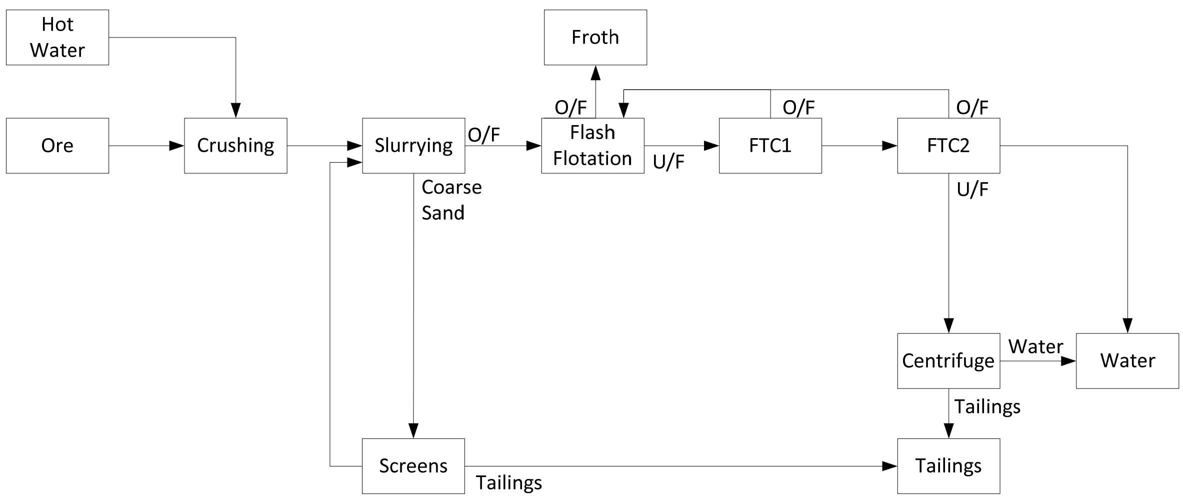


Figure 4 - Phase 1 & 2 bock flow diagram

6.2 Phase 2

A cone crusher (see photo D.4) was trialed in Phase 2 of the project, replacing the rental crusher. The rest of the process was kept essentially the same as shown in Figure 4. Unfortunately, the cone crushers were deemed unsuitable as they were not able to provide a consistent product of appropriate size. In Phase 2 a small scale belt filter was tested, and as it showed promise, a full-scale unit was added to the design in Phase 3.

Operation of Phase 2 occurred from Nov 2018 to May 2019.

6.3 Phase 3

Along with a full scale horizontal vacuum belt filter (HVBF, see photo D.14), a cyclopac of four cyclones (see photo D.9) was added in Phase 3. Figure 5 shows the Phase 3 flowsheet (also shown in photo D.1). Underflow from the second flotation cell now feeds the cyclones instead of the flotation cell 3. The cyclones separate the tailings into coarse material (underflow) that feed the belt filter for further dewatering and fine material (overflow) that feeds flotation cell 2. The dewatered belt filter tailings are deposited to the tailings conveyor. The fine solids overflow from the cyclones now feeds flotation cell 3.

In Phase 3, the rental recycle water tank was also replaced with a purchased tank (see photos D.10, D.11, D.12). Though it is not shown in Figure 5, any bitumen that builds up on the water tank is able to overflow back for to flash flotation.

Phase 3 operated from June 2019 to Aug 2019.

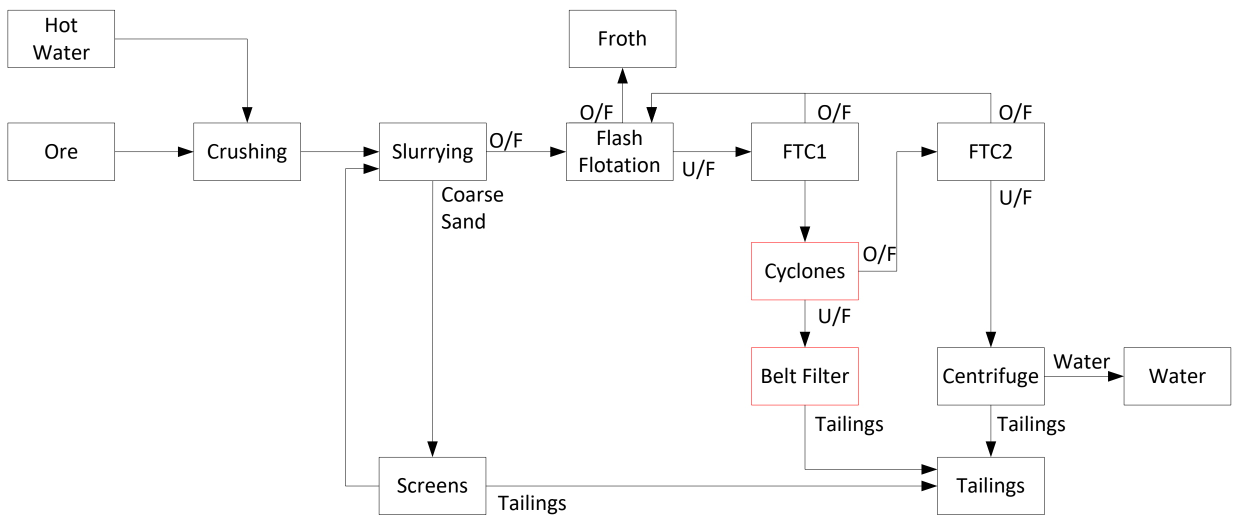


Figure 5 - Phase 3 block flow diagram

6.4 Phase 3B

Phase 3B (Figure 6) included four major changes:

- Installation of purchased conveyors, replacing the rental conveyors(see photos D.2, D.3);
- Installation of two stage sizers (see photos D.3, D.5), replacing the cone crusher;
- Installation of a thickener(see photos D.10, D.11, D.12); and
- Bypass of the screens.

The two stage sizers crush the material to 2”. Hot water is added to the first stage sizers to ensure the material moves through the sizers.

The thickener was added as a process step between the third flotation cell and the centrifuges. It was intended to help thicken the feed to the centrifuges and provide a denser, more consistent feed, allowing for a reduction in the number of centrifuges required. Clean water that overflows the thickener is combined with the centrate water from the centrifuges.

The coarse material augered up by the washer screws is directed to the belt filter for further dewater, eliminating the vibrating screens from the process.

Phase 3B was operated from Nov 2019 to February 2020 with limited runs due to an extended shutdown of the utility source and IPEP maintenance, and concluded prematurely due to 2020 world events and mitigation of impacts of same on Canadian Natural’s operations.

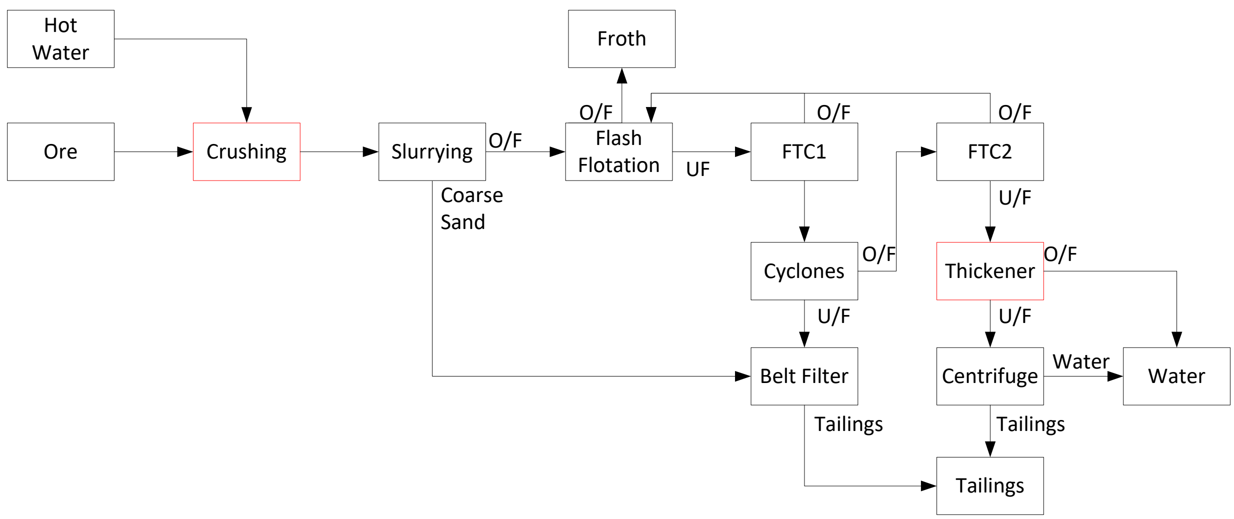


Figure 6 - Phase 3B block flow diagram

7 IPEP Unit Operations

This section of the report is mainly qualitative, discussing the overall process of trialing the different technologies, process changes made, what worked well, and technical issues identified/rectified leading to final Phase 3B design. The following supplemental information can be found in the appendices of this report:

- IPEP 500 Process Drawings
  - Appendix A – IPEP 500 Phase 3B BFD
- The Material Balance and coordinating Stream and Sample Points Drawing
  - Appendix B – IPEP 500 Phase 3/3B Streams and Samples Points
  - Appendix C – IPEP 500 Phase 3B Design Mass Balance
- Photos of equipment and operations
  - Appendix D – IPEP 500 Photos

In Phase 3B, the pilot's target ore feed rate was decreased from 500 t/h to 375 t/h to accommodate the capacity of the HVBF. Operations did succeed in meeting the 375 t/h target on an intermittent basis, however on an average the maximum was 325 t/h.

7.1 Crushing & Conveying

Within IPEP 500's scope, Bulk Material Handling (BMH) comprises the conveyor and crusher systems used to transport and size the feed ore prior to slurrying, as well as conveyors used to haul tailings to stockpile for disposal.

Overall, the crushing process worked well, and further optimization of this aspect of the process is straightforward, as a well-established technology in oil sands.

Lessons learned include:

1. Ore feed size is critical for crusher operation.

2. Use of a cone crusher (Phase 2) was not optimal for the process, as it occasionally allowed oversized ore to fall through the larger open side, leading to plugging of the slurry pumpbox. The issue was mitigated by pre-screening the ore prior to feeding it into the cone crusher.
3. Wet sizers (Phase 3/3B) were an improvement over the cone crusher in regards to mitigation of oversized lumps sent to the pumpbox. The main issue encountered with wet sizers was wear and damage to the teeth. The units were not originally designed for wet use, and the water addition led to continuous removal of the material between the teeth and the shaft, allowing them to rattle and break free. The ring cap style alignment of the teeth may also have allowed for increased wear as the ore was crushed against the back of the teeth instead of between the teeth on opposite rolls. A platen style tooth would eliminate this issue. Overall the wet crusher performance improved with the new wet sizers, and pumpbox plugging issues were resolved.
4. On the tailings side, tailings from the belt filter, screens, and centrifuges were deposited onto a series of conveyors. While this system worked well when the plant was operating well, the main challenge on the tailings side was off-spec material. Since off-spec tailings is wetter than normal, problems were experienced with material running off from the underside of the conveyor and impacting the rollers and associated mechanical components, bridging/building up in hoppers, freezing to conveyors, overflowing from conveyors, etc. These issues are typical for conveyor systems and a number of solutions have been identified to mitigate them. A belt wetting system was adopted as part of winterization measures which helped significantly to address the freezing problems on the ore feed conveyor. The impact zones on the conveyors also tended to incur more damage than anticipated, requiring roller replacement – another issue that can be mitigated easily with small design adjustments.
5. The crushers and conveyors constituted the largest impacts on reliability and availability within the IPEP operations, as discussed in Section 8 - Pilot Reliability. The positive outcome of this finding is that these are well-established technologies in oil sands, and it is fully within reach to resolve their issues, which will thereby significantly improve the overall plant reliability.

7.2 Slurrying

The equipment included in the slurry steps of IPEP 500 were: crusher pumpbox and pump, fine and coarse washer screws, the dewatering screens, screen underflow (U/F) tank, and associated piping.

Lessons learned include:

1. Pressure transducers provided more accurate and reliable measurement of level in vessels (density compensated level).
2. The washer screws are a new technology for oil sands, and the crew learned a great deal in short order about its operation for slurry ablation. The screws performed quite well – ore ablation was good, no issues with rocks or sand plugging, and the wear incurred on the screw flights was surprisingly minimal, particularly considering their application.
3. Modifications to the feed location in the screws helped ensure even distribution of feed and reduce turbulence at the O/F, which in turn also led to a noticeable improvement in performance. The washer screw O/F weirs were modified (as permitted within the layout constraints) to increase their area and promote froth O/F while minimizing turbulence. The positive change in performance with limited weir modification suggests the weir design could be further refined for process optimization.
4. Screws are capable of handling 375 t/h throughput and functioned well under all ore grades. Downstream belt filter capacity led to reducing the target plant capacity to 375 t/h ore feed, and the decision was made to operate on a single train of washer screws. A single coarse screw's feed was increased from 250 t/h (500 t/h split between two trains) up to 375 t/h. During operations, 350-375 t/h was successfully achieved on one screw train for brief periods without adverse performance impacts. Maximum averaged plant throughput was in the region of 325 t/h, not limited by the screws.

5. Different screen mesh sizes were tested, and different delivery locations for the screen underflow (U/F), before settling on the final Phase 3 arrangement. Phase 2 saw issues with the vibrating screens where the mounting plate and feet cracked due to a manufacturer's design flaw, which was remedied. In Phase 3B the team trialed bypassing the screens for direct discharge of the fine screw U/F onto the belt filter, though the plant only operated in this configuration for a short period of time (< 2 months).
6. Sampling considerations are required when designing future coarse and fine washer screw stacking configuration

7.3 Flotation Circuit

The Flotation Circuit consists of the Flash Flotation Tank (FF), Flotation Cells 1 and 2 (FTC1/2), macerator, and the associated pumps and piping. The cyclones are closely associated with the flotation circuit but are discussed in a separate section.

Lessons learned include:

1. The overall performance of the flotation circuit was good. Optimization is certainly within reach, as this is a well-established processing technology in oil sands.
2. Pressure transmitters used to estimate vessel level (density compensated level) performed better that the sigh glasses and cameras for froth/middlings interface monitoring.
3. Spargers initially installed in the flotation cells were observed to generate large air bubbles, which are not ideal for bitumen attachment and flotation as they require micro-bubbles. The spargers were replaced with plunging jets installed on the feed nozzles to the flotation cells for Phase 3, to increase air entrainment in the slurry. Bitumen flotation was improved with this change.
7. A macerator (inline grinder) was used to reduce the size of coal and/or other low-density solids present in the slurry prior to cycloning. This material is naturally occurring in the ore, and tends to float at an SG of approximately 1.2. If sufficient material accumulated in the middlings and/or the fluid density in the vessel decreased, these solids would settle abruptly, plugging the pump and/or macerator. Note that this phenomenon is not unique to IPEP, it is also observed in the main plant.
8. Options to replace the macerator with a screen should be examined as the macerator experienced high wear.

7.4 Froth

One of the unique challenges of IPEP is the change to the slurrying process, which changes the froth produced and how the bitumen is delivered to the plant. Canadian Natural's conventional approach is via hydrotransport lines with significant water and solids content, and well-known slurry pipeline modeling tools. Elsewhere in the plant, high-quality froth pumping (with lower water and solids content) is also represented by well-established froth pipeline modeling tools.

Lessons learned include:

1. The froth that was produced in IPEP 500 is of a middle range between slurry hydrotransport and bitumen froth pumping systems, and this presents a challenge for proper pipeline design, as no fluid models exist for this region. Proper pump selection/placement and pipeline design for this system is further complicated by the high air content in the froth. As the bitumen content is significant, temperature also contributes greatly to the fluid's behavior.
2. Phase 3B was to include a campaign to trial the froth cleaner, however piloting was stopped before it could be trialed. The froth cleaner was intended to further reduce the water content of the froth, bringing it in-line with the existing plant's froth quality and enabling higher confidence in the froth pipeline modeling and pump selection.

7.5 Cyclones (Phase 3)

Small diameter cyclones were trialed in Phase 1 & 2, as a dewatering step before the small trial belt filter. The apex and vortex finder size were adjusted to find an optimal configuration for achieving best feed composition to the belt filter.

A cyclopac was then procured and installed for Phase 3 operations along with the HVBF. The cyclopac received FTC1 U/F as feed, with the cyclopac U/F reporting to the full-scale belt filter and O/F feeding FTC2.

Lessons learned include:

1. The cyclones were found to also promote bitumen recovery via air entrainment in the cyclone O/F stream, and downstream recovery via the FTC2 O/F. Very little wear was observed on the cyclones.
2. Cyclones showed little wear during operation
3. Alum was an effective dewatering aid when added to the cyclone U/F.
4. A larger number of smaller cyclones would provide better operational flexibility by enabling fine-tuning of the cyclone operations with variation in feed

7.6 Thickener (Phase 3B)

A thickener was added to the process to improve consistency of feed to the centrifuges, and assess the potential for optimizing centrifuge operations. A small thickener was trialed in Phase 1 and the data was used to procure a full-scale high-rate thickener from a vendor for Phase 3B. The new full-scale unit arrived on-site in fall 2019 and was installed for Phase 3B operations.

Lessons learned include:

1. Thickener underflow density was consistent; however the clarity of the O/F was less than desired. As thickeners are a well-established technology in-use at both Horizon and Albian, optimization is expected to be achievable.

7.7 Belt Filter (Phase 3)

A small horizontal vacuum belt filter (HVBF) was trialed in Phases 1 and 2, with promising results leading to procurement and installation of a 75 m^2 unit, the largest commercially available in the timeframe available for Phase 3 operation.

Lessons learned include:

1. The overall operation of the belt filter was a positive experience and met targets for cake solids content. Feed blending, feed distribution, and bed thicknesses were varied to determine optimal ranges, with success. An even distribution of solids across the belt filter was achieved without difficulty; the belt filter was flexible in operation and could be adjusted to change the cake thickness and achieve the target dryness. There were no issues with plugging of the feed box, and the operation was easy to monitor visually and adjust with quick results; process issues were apparent fairly quickly (within ~10 minutes) and once rectified, normal operations resumed just as quick.
2. One of the main issues experienced with the HVBF related to cloth cleaning, including bitumen and clays clogging the cloth, trialing use of solvents and hot water for cleaning, nozzles plugging with solids. The cloth plugging issue was addressed by changing to a looser cloth weave. A longer term operation of the belt filter would be required to assess cloth lifespan, for both plugging and durability.
3. The alum was found to be an important additive for HVBF operations, without it there were problems with achieving sufficient dewatering for material handling by the conveyors, particularly with high fines ores. Adjusting the alum dosage showed performance results within minutes.

4. The screen bypass deposit location was designed to deposit the washer screw U/F material onto the formed cake to mitigate any negative impacts of rocks impacting the filter cloth. This worked well and no issues were observed with rocks being deposited on top of the cake. In addition, the belt filter performance did not appear to suffer with the additional material from the screws.

7.8 Centrifuges

Large Lynx 1000 centrifuges were initially installed in Phase 1. Lessons learned include:

1. Though there were issues with centrifuge performance, torque, and centrate quality, the cake solids content was quite consistent. Issues with the larger centrifuge were thought to be a factor of feed variation, which was addressed with the addition of the thickener upstream to regulate the centrifuge feed consistency.
2. Smaller centrifuges may be considered to handle greater range of operation.

7.9 Tailings

Tailings production has been discussed in the prior sections.

A critical aspect of IPEP 500's performance is establishing a tailings product with adequate geotechnical properties for conveying and dumping/spreading into a disposal area.

Lessons learned include:

1. Though there were issues with centrifuge performance, torque, and centrate quality, the cake solids content was quite consistent. Issues with the larger centrifuge were thought to be a factor of feed variation, which was addressed with the addition of the thickener upstream to regulate the centrifuge feed consistency.
2. Smaller centrifuges may be considered to handle greater range of operation.

7.10 Reclaim Water

All reclaimed water was collected for re-use in the pilot as required, from the filtrate, centrate, and thickener overflow streams.

Lessons learned include:

1. Bitumen tends to stay with the water streams and overflows in the process. Reclaim water tank design allowed for recovery of bitumen and re-introduction back to the flotation circuit.
2. Solids content was higher than desirable, and without a regular drain of reclaim water, fines buildup may become a long-term operational issue due to continuous recycling of water within the pilot and minimal dumping of excess water. Part of this issue may also be mitigated with optimization of the thickener operations.
3. The addition of alum to the process is beneficial for tailings dewatering, but negatively impacts bitumen recovery. Filtrate from the belt filter containing alum may therefore ultimately not be ideal for re-use via the reclaim water system. To avoid the impact of tailings chemistry on extraction performance, one strategy would be to divert the filtrate directly to a dump line.

7.11 General Operations

One consequence of the pilot using full-scale equipment and vessels is that the layout afforded little flexibility in accommodating retrofits of additional equipment and pipelines. The cost of re-doing the plant layout (de-commission, demolition, move, re-build, re-commission) would have been exorbitant. Process monitoring issues resulted due to insufficient straight pipe lengths for metering, and accessibility issues for manual sampling.

The plant operations are also generally conducted indoors, and some areas are high-humidity, steamy environments, as such, good building HVAC will be important. This has been also observed in existing operations.

Lessons learned include:

1. Ensure plant layout spacing to allow for sufficient upstream and downstream straight-run requirements for flow metering.
2. Ensure ample flush ports and drains to help clear plugs.
3. Minimize elbows and horizontal sections in piping drains to prevent sanding off.
4. Ensure adequate HVAC for high-humidity indoor operations.

8 Pilot Reliability

Figure 7 presents an overall view of the IPEP 500 operating campaign timeline. Pilot run durations are shown, along with distinction of the specific pilot Phases and optimization work (installation/commissioning of equipment).

One of the major objectives of the pilot was to work towards achieving continuous 24 h operations, Figure 7 shows that the process modifications were successful in working towards that goal with increasing average run times:

- Phase 1 -- 290 min
- Phase 2 -- 404 min
- Phase 3 -- 540 min
- Overall average run time 422 minutes (~7 h per shift)

It is noted that Phase 3B of the campaign would have been the next operating phase after the construction work in Fall/Winter 2019. Only a few operational runs were achieved during this Phase due to utility downtime and IPEP maintenance; full scale operations were set to resume in Spring 2020.

Downtime events had a significant impact on the frequency and duration of pilot operation. Figure 8 and Figure 9 demonstrate the main culprits for the number and duration of downtime events. It is noted that the charts only show operational downtime and construction activities are not included, though they did result in significant time that the pilot was not operational.

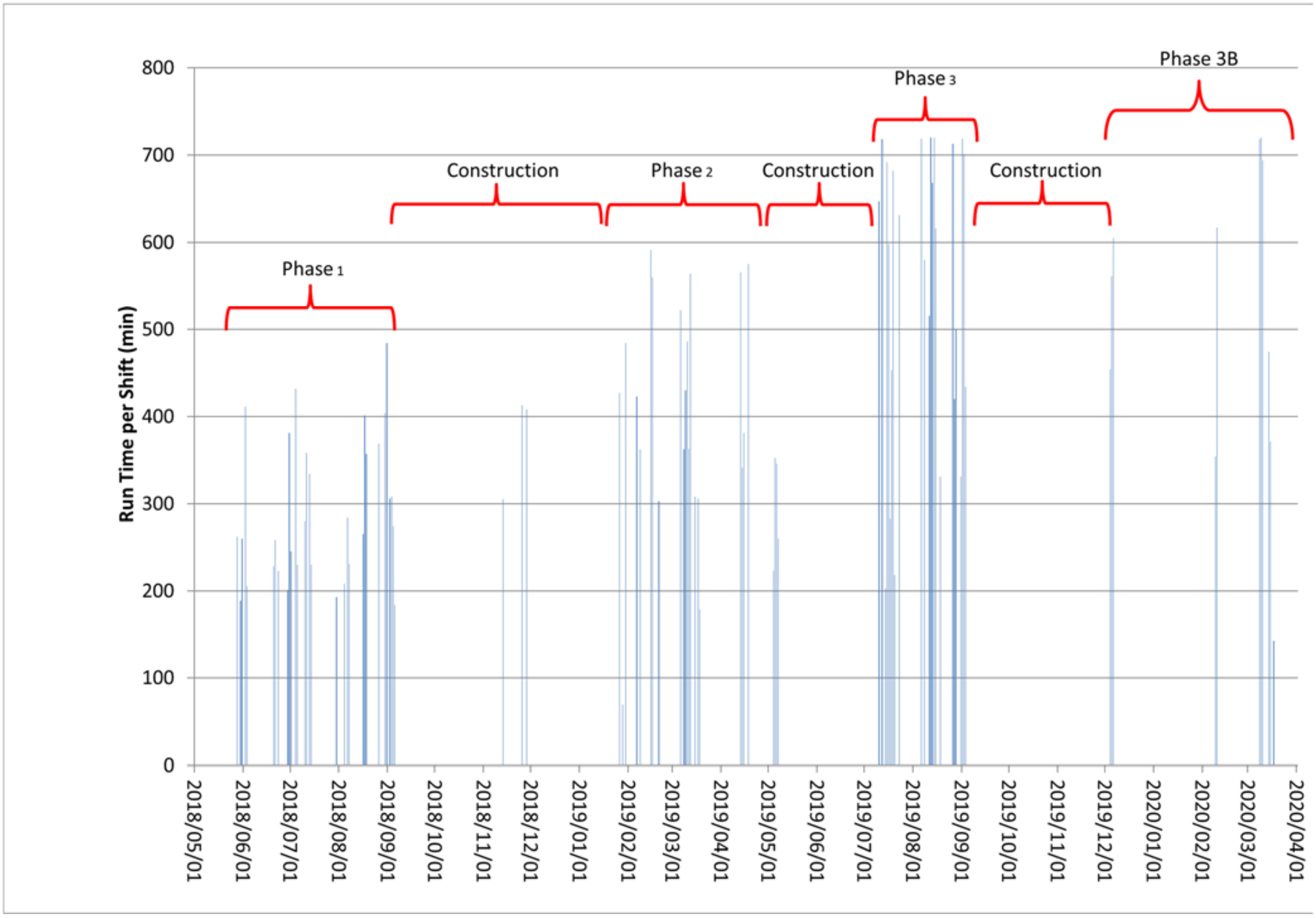


Figure 7: IPEP 500 operation phases with run times (with phases and periods of construction shown)

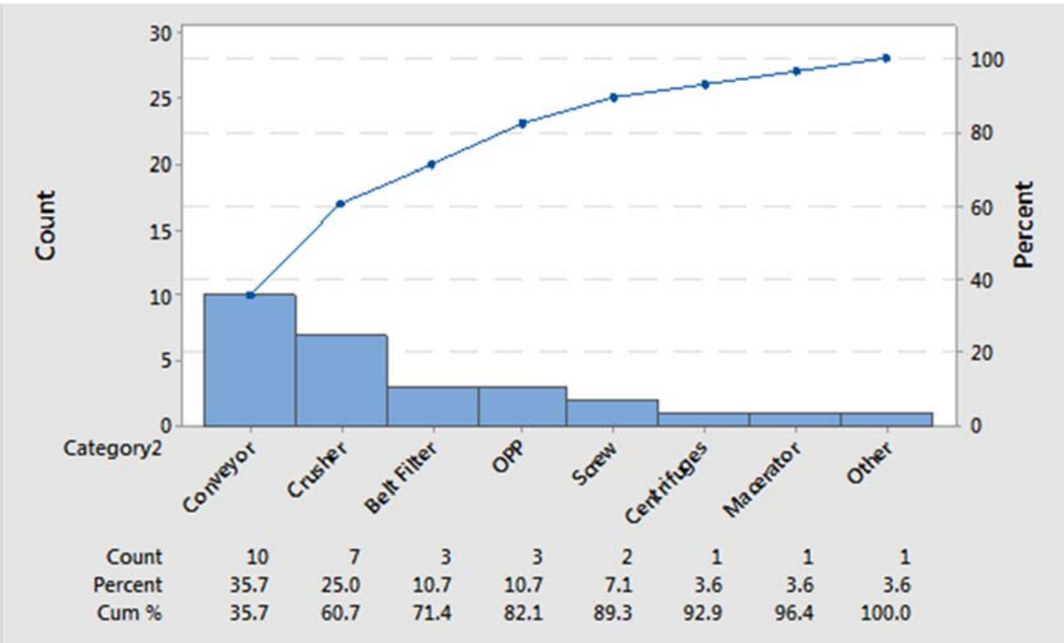


Figure 8: Pilot downtime events by count

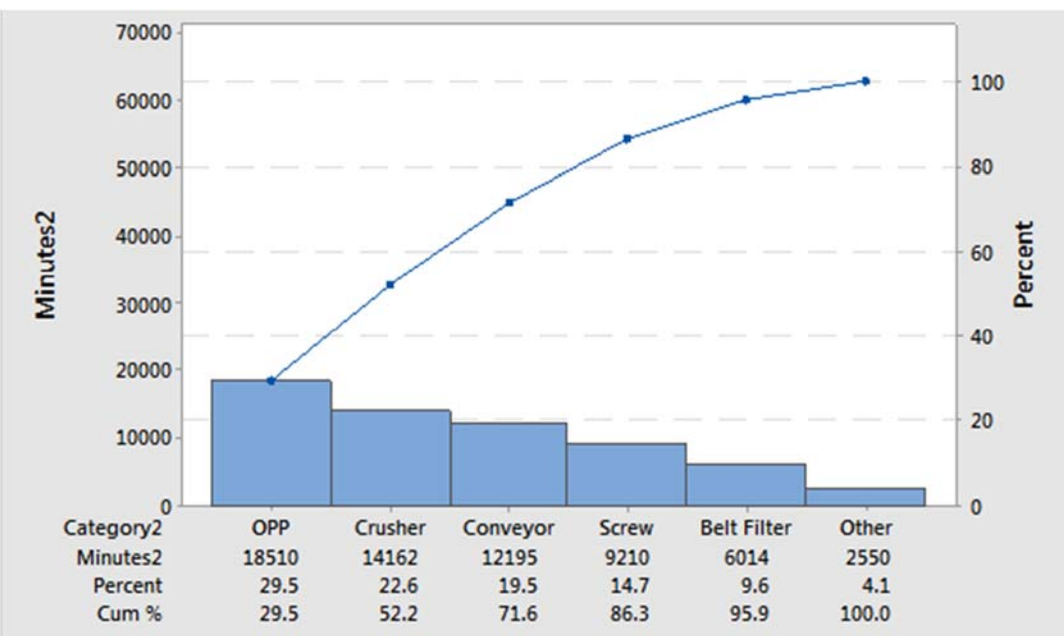


Figure 9: Pilot downtime event durations (in minutes)

The primary causes for downtime within IPEP 500 itself were the conveyors and crushers, causing a combined 60.7% of downtime events and 41.2% of the total downtime incurred for maintenance and repairs. Another major factor was the availability of utilities at the tie in point – any time they were down for maintenance, IPEP 500 could not operate.

The mechanical issues with the crushers and conveyors are discussed in Section 7.1. The IPEP team has investigated alternative technologies to address these reliability issues, such as crusher tooth configuration. They have been proposed for trialing in future IPEP piloting.

9 Pilot Data and Data Processing

The following sections provides information on the pilot data collected during IPEP 500 operations, and the BILMAT models used for data analysis.

9.1 Data Analysis Overview

Raw pilot data generally has redundancies and inconsistencies from a material balance viewpoint, due to natural disturbances, sampling errors, unreliable instrument readouts and laboratory analysis inaccuracies. This makes it difficult to use raw data directly in the calculation of mass balances and quantification of equipment performance within an ore processing and flotation circuit – a statistical analysis approach is required.

BILMAT is a program developed for calculating material balances in mineral processing and flotation circuits, available through the Canadian Institute of Mining, Metallurgy and Petroleum. The program's algorithms upgrade ore processing data, adjusting them in a least-squares sense to produce statistically reconciled steady state mass balances. The program is also able to determine best values of unmeasured flow rates.

The single node model was developed for daily use during pilot optimization to monitor KPIs, as its simplicity enabled evaluation on a daily basis using core process data and consistent modelling across all pilot configurations and concept changes.

Analysis and discussion of the raw data produced by IPEP 500 is primarily limited to data collected during Phase 3 and 3B, as the most optimized version of IPEP with longest run-times to-date. Some data from Phase 1 and 2 was included to provide additional information in regards to feed quality variance, however changes to the overall pilot configuration during these Phases limited their usage in mass balances for the final pilot configuration.

9.2 Data Collection

Data for this pilot was recorded in a historian system, including both on-stream instrument readings and laboratory analysis results from collected stream samples.

Manual sampling was performed by dedicated samplers following a set route throughout the plant. As such, samples were not collected simultaneously but over a short time span. Dedicated sample points were assigned numbers for tracking in the Pi Historian, also identified by numbered tags on the IPEP 500 P&IDs (see Appendix B– IPEP 500 Phase 3/3B Streams and Samples Points for drawings with sample locations). Samples were collected in different ways depending on the stream and access including via sample port valves (such as vessel underflows), dipper cups on long poles (such as overflows), and on-stream autosamplers.

Stream samples for laboratory analysis were collected as 2-hour batches in 4 L cans, filling the can ~¼ full every half hour. These samples were only collected once the pilot had achieved 4 h of continuous operation, at which point the system was declared to have achieved "steady state". If the pilot operations deviated substantially during the early portion of the 2 h window of sampling, sampling was stopped and the collected samples were discarded.

Canadian Natural's main laboratory at Horizon (operated by Maxxam Analytics) handled the processing and analysis of the pilot samples in accordance with normal production sample analysis procedures. Collected samples were taken to the lab once per day for the following work:

- Sample homogenization and subsampling
- Dean Stark analysis for bitumen, solids and water content
- Laser diffraction particle size analysis on dry solids samples (fine / coarse)

The raw data consists of Dean Stark and particle size distribution (PSD) analysis of composite samples from various streams, as well as instrumentation readings (flowmeters for slurry and water streams and weightometers for ore and dry tailings streams).

For sample point locations, please refer to the diagram in Appendix B – IPEP 500 Phase 3/3B Streams and Samples Points.

Though a great deal of data was collected during pilot operations, it is acknowledged that some gaps in the raw data exist for certain areas of the process. The operations team noted that some streams were difficult or impossible to monitor directly via manual sampling or instrumentation. This was partially due to the “in-development” nature of the full-scale pilot – adding units and changing streams within the confines of the existing equipment layout led to congestion and accessibility issues.

- Flow metering instruments require sufficient uninterrupted straight-run lengths to function well, not always possible in a retrofit line.
- Density measurements are unreliable for slurry due to the proximity of densities of water and bitumen, and slurry solids profile variance.
- Some streams were logistically problematic for safe access to achieve proper representative sampling, like the coarse screw underflow to the fine screw.
- Some vessel overflows were only accessible by tall ladders in steamy environments, making them an “only when critical” sample point.

The data gaps do not affect the Single Node modeling but do impact a Multi-Node analysis.

There is also less than an ideal amount of complete data sets suitable for use in the Multi-Node analysis due to premature termination of the pilot campaign. Phase 3B was shut down prematurely in March 2020 due to COVID-19, as Canadian Natural had to protect main production operations by limiting access to site to core personnel only.

9.3 1-Node Model

Data collected from the major inlets (source) and outlets (sink) streams of the plant were reconciled on a daily basis via the 1-Node model.

The 1-Node model’s purpose was to understand plant performance with respect to feed rate (ore tonnage), froth quality (bitumen and solids content in the froth stream), tailings dryness (whole tailings solids content), bitumen recovery, hot process water (HPW) usage and recycle water (RW) quality (bitumen and solids contents). The data reconciled this way are referred to as the 1-Node model or 1-Node mass balance or simply “Reconciled” in this report.

Streams used in the 1-Node balance are shown in Figure 10.

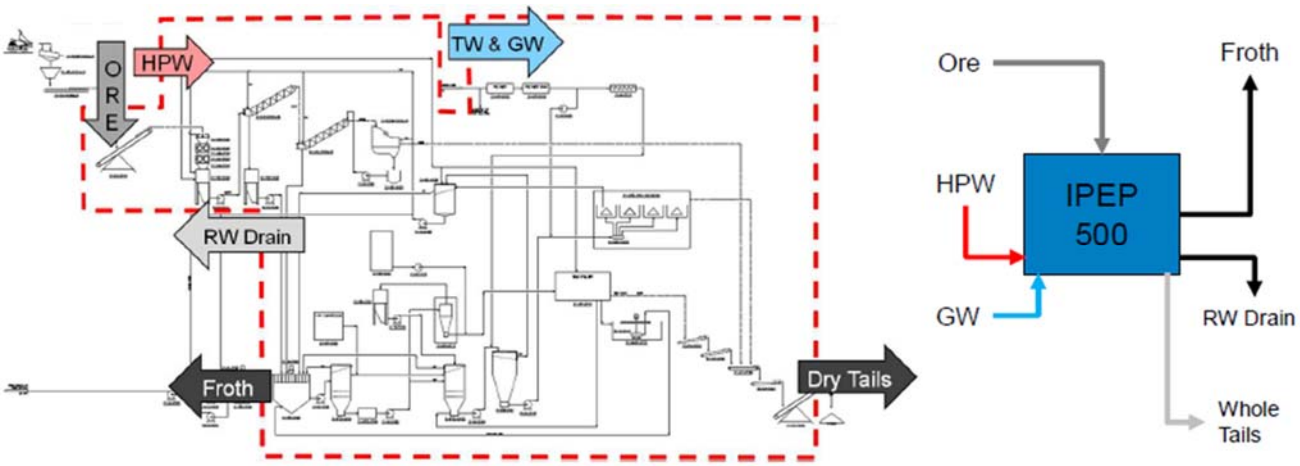


Figure 10: 1-Node mass balance model

10 Results

10.1 Ore Throughput / Feed

Ore tonnage varied from 200 to 400 t/h across all three Phases and averaged 300 to 325 t/h in Phase 3/3B as shown in Figure 11. Looking at ore grade, bitumen content varied from ~6-15 wt% (Figure 12a) and fines content from <4 to >40 wt% (of total solids, Figure 12b). As expected, the fines content generally decreased with increasing bitumen content (Figure 13).

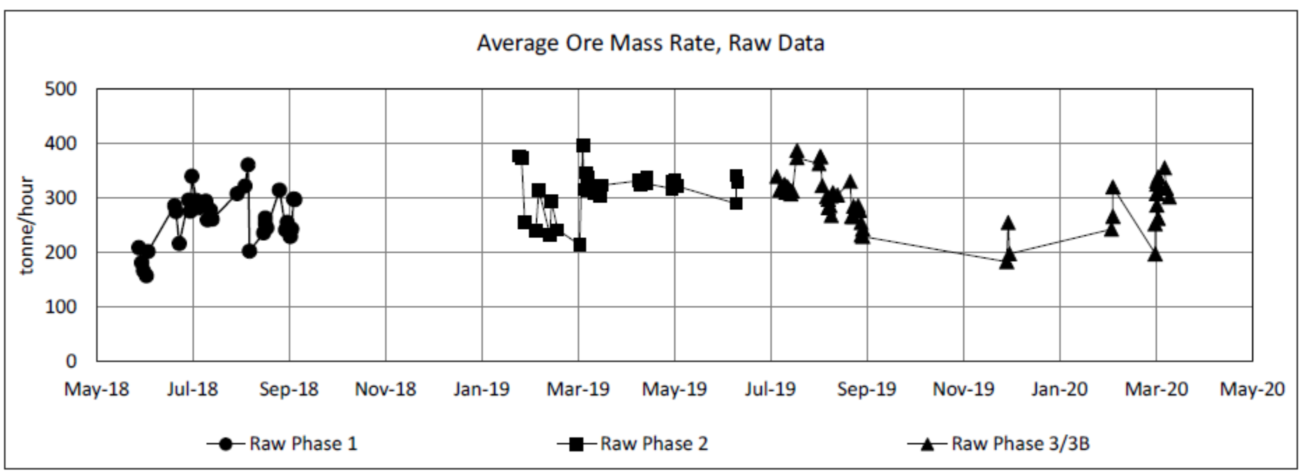
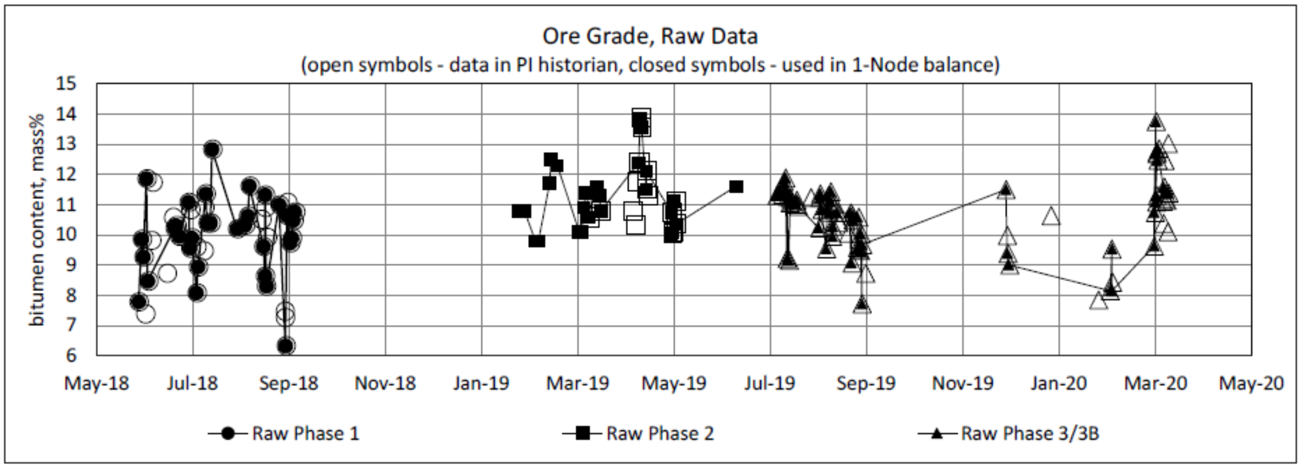


Figure 11: Raw ore tonnage



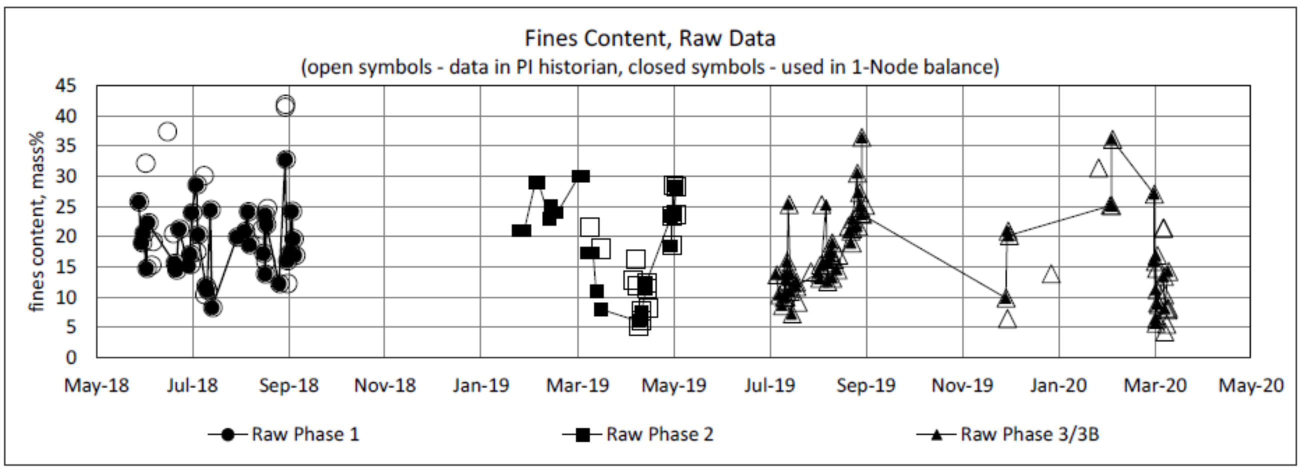


Figure 12: Raw bitumen content (a) and fines content of ore (b)

Water content varied between <1 to ~10 wt%, with most data in the 3-6% range. Average water content for Phase 1, 2, 3/3B was 5.3%, 2.7%, and 4.1%, respectively.

Figure 14 compares raw and reconciled (1-Node) data for ore tonnage and bitumen content and shows the reconciled data tends to be higher than the raw for ore tonnage and lower for bitumen content.

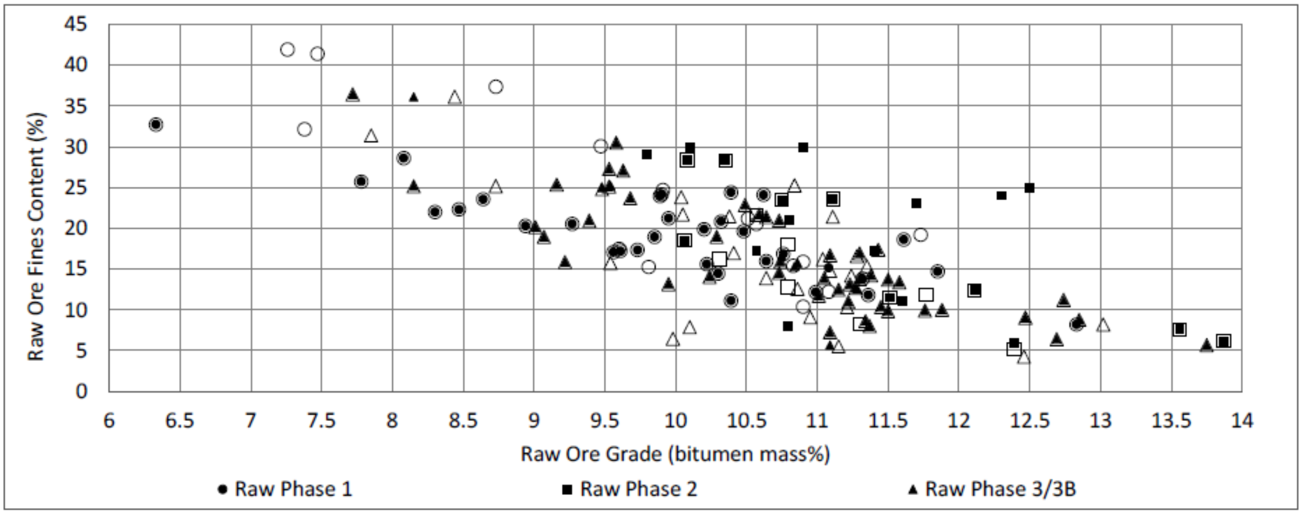


Figure 13: Fines content as a function of ore grade for Phase 1, 2, 3/3B

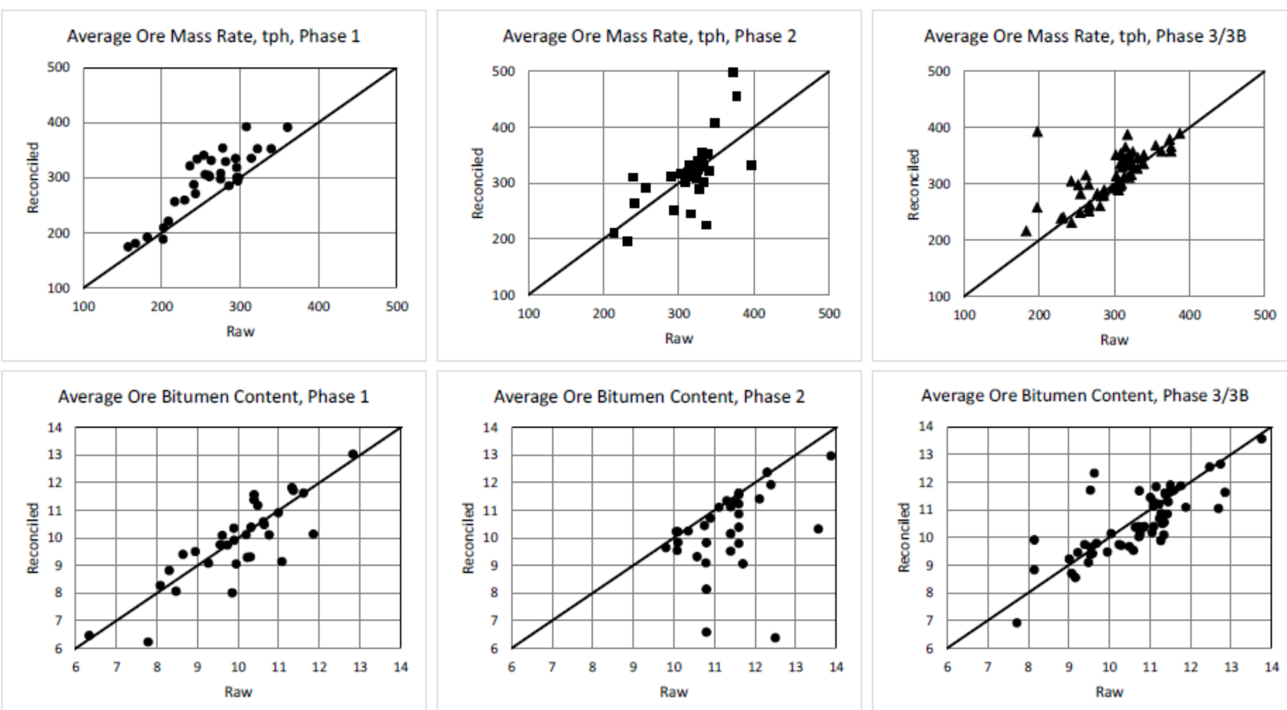


Figure 14: Comparison between raw and reconciled ore tonnage and grade

Though a range of ore was sought for all Phases, the availability of ore (based on current mining) as well as the objective to achieve longer run times did limit the types of ore used in the plant at times. Ore grade ranged from ~7-14 wt% bitumen (average 10.7 wt%) and 5-37 wt% fines (average 16.6 wt%). The feed quality was the lowest during Phase 1 and highest in Phase 2, with Phase 3/3B covering a wide range of ore qualities. In general, raw and reconciled (1-Node) data match well, however the reconciled data tends to shift the low grade ores higher, and the high grade ores lower (in terms of bitumen content).

10.2 Bitumen Recovery

The reconciled data sets from the 1-Node mass balance were used to calculate bitumen recovery. IPEP bitumen recovery is equivalent to the bitumen recovery steps of OPP and Extraction in the main plant and does not include Froth Treatment. Therefore this metric should not be compared to recovery curves defined in Section 2 of AER Directive 082 (Equation 1, above).

Overall bitumen recovery can be calculated in several ways. If using raw data, Equation 2 is recommended as it does not involve froth tonnage (which was particularly biased due to fairly significant bias in the closure of raw Dean Stark data (on average during Phase 1, 2 and 3/3B, 0.7% of expected mass was missing). Note that normalizing raw composition to 100% closure prior to mass reconciliation is not recommended, since *a priori* assumptions of proportionality in error distribution should be avoided.

$$R_B = \frac{M_O x_{B,O} - M_T x_{B,T} - M_{RWD} x_{B,RWD}}{M_O x_{B,O}} \qquad \text{Equation 2}$$

where:

R	=	Recovery (%)
M	=	Mass Flow (t/h)
x	=	Mass Fraction (ie $x_{B,T}$ is mass fraction of bitumen in tailings)
B	=	Bitumen
O	=	Ore
T	=	Tailings
RWD	=	RW Drain

Reconciled overall bitumen recovery is provided in **Error! Reference source not found.**, and the reconciled recovery is compared to the raw data in Figure 15 (calculated using Equation 2). In general, the reconciled bitumen recovery is higher than the raw, particularly in Phase 1 (0.8% absolute) and 3/3B (1.6% absolute).

Table 4: Reconciled bitumen recovery for three bins of ore grade in Phase 3/3B

	Reconciled Bitumen Recovery		
	Ore Grade <9%	9%< Ore Grade <11%	Ore Grade >11%
Numerical average	83.7	90.7	92.8

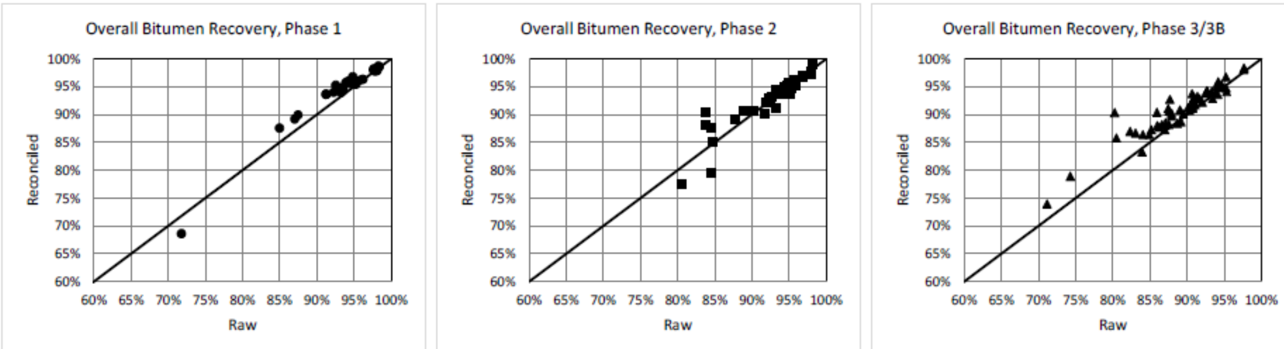


Figure 15: Comparison between raw and reconciled overall bitumen recovery

Ore grade is one of the parameters that impacts bitumen recovery, though it does not show a strong trend in Figure 16. However, it can still be inferred that in general, higher recovery was achieved at higher grade, and vice versa. This is shown in **Error! Reference source not found.** and Figure 18 which shows the percentage of occurrences of very poor recovery (<92%[1]) and very high recovery (≥95%) for three ore grade bins, by Phase. In general, as the ore grade increases, the frequency of poor recovery decreases (and frequency of high recovery increases) during each Phase.

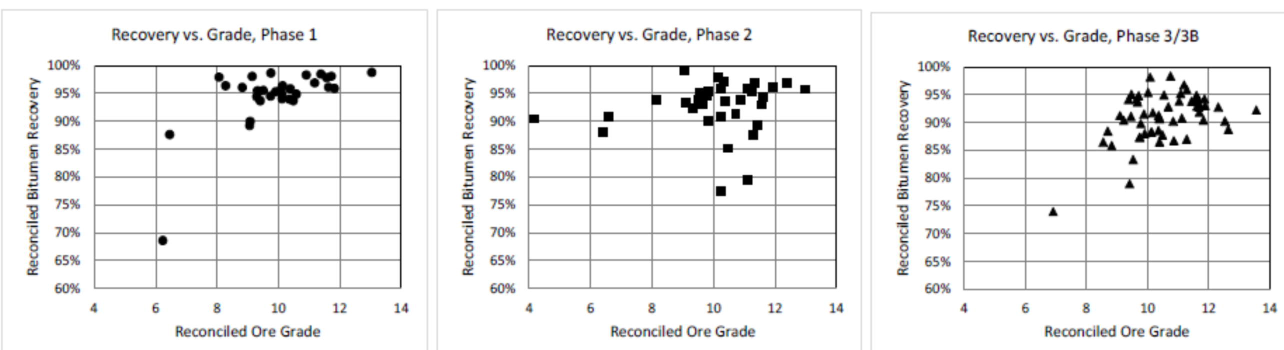


Figure 16: Overall bitumen recovery as a function of ore grade. All values are reconciled from the 1-Node balance

[1] Very low recovery is selected at 92%, which is equivalent to ~90% recovery once froth treatment is taken into account. Very high recovery is somewhat arbitrarily chosen as ≥95%).

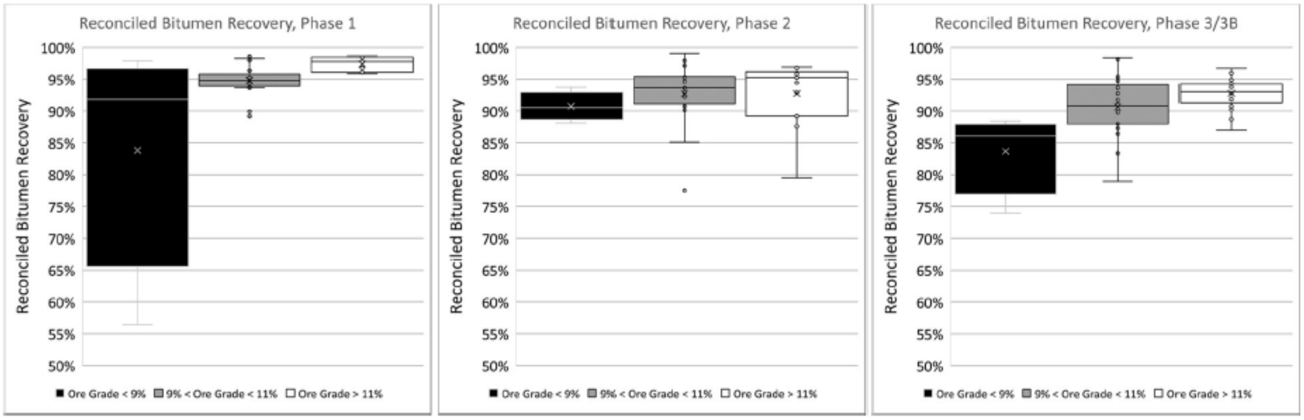


Figure 17: Box and whisker plots of reconciled bitumen recovery at three ore grades (bins) for each Phase

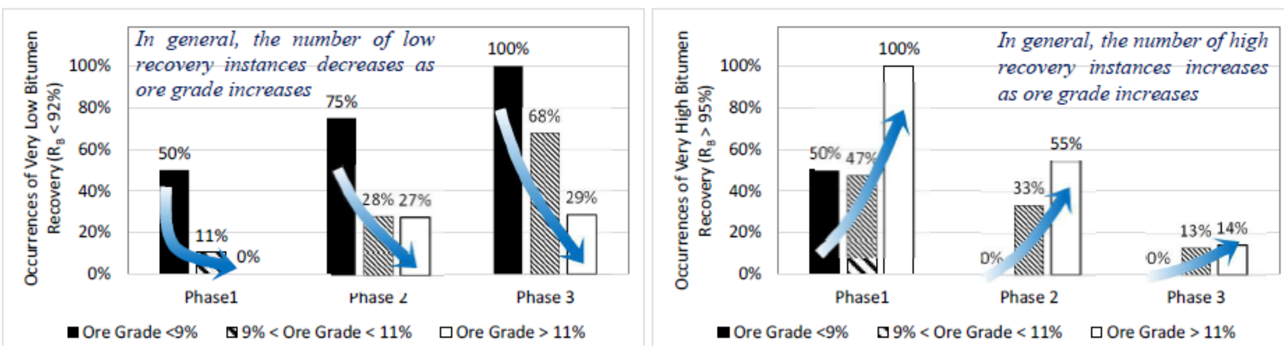


Figure 18: Occurrences of very low bitumen recovery (RB < 92%) and very high (RB > 95%) recovery for three bins of ore grade (all values are reconciled form the 1-Node balance)

10.3 Froth

There were many challenges in both pumping and measuring the froth stream and as such there are uncertainties in the flow measurement. Raw froth flow rate is shown in Figure 19 (without accounting for the impact of ore throughput on the amount of froth produced). Raw and 1-Node reconciled data are compared in Figure 20. Other streams (ore, tailings, etc.) drove the reconciled balance resulting in large deviations to the froth rate.

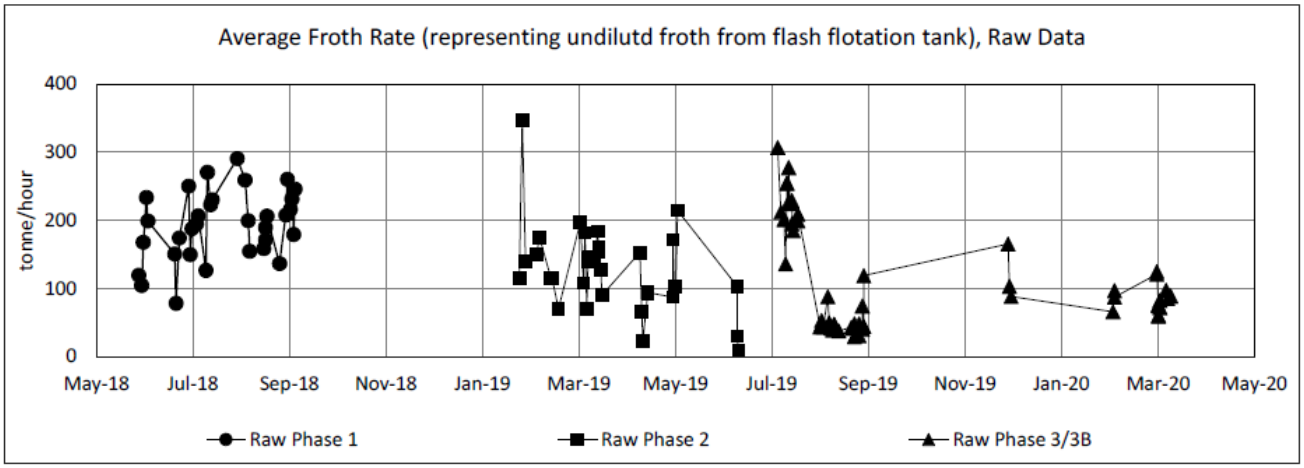


Figure 19: Raw, undiluted froth rate

Froth sampling was possible from two locations – directly from the side of the froth tank ("undiluted") or from an autosampler after the addition of dilution water ("diluted").

Reconciled data indicated that froth quality improved from Phase 1 to Phase 3. Raw and Reconciled data showed good alignment for each component and Bitumen to Mineral Solids (B/MS) ratio.

Undiluted froth composition (raw data) is shown in Figure 22a, and B/MS (raw data) is shown in Figure 22b. There were many instances of low froth quality during Phase 1 and 2, with higher froth quality observed in Phase 3. Raw vs 1-Node reconciled data is shown in Figure 21 with data for Phase 1 and 3/3B showing good alignment for each component and B/MS.

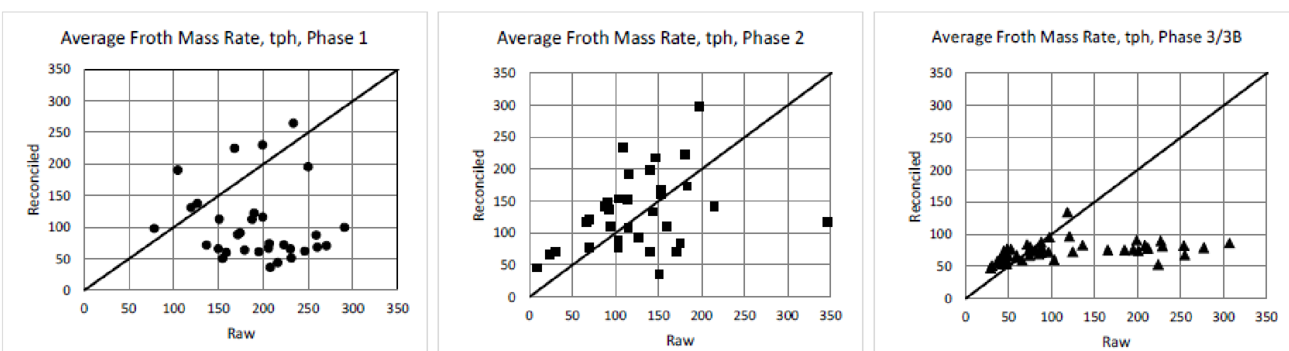


Figure 20: Comparison between raw and reconciled undiluted froth tonnage

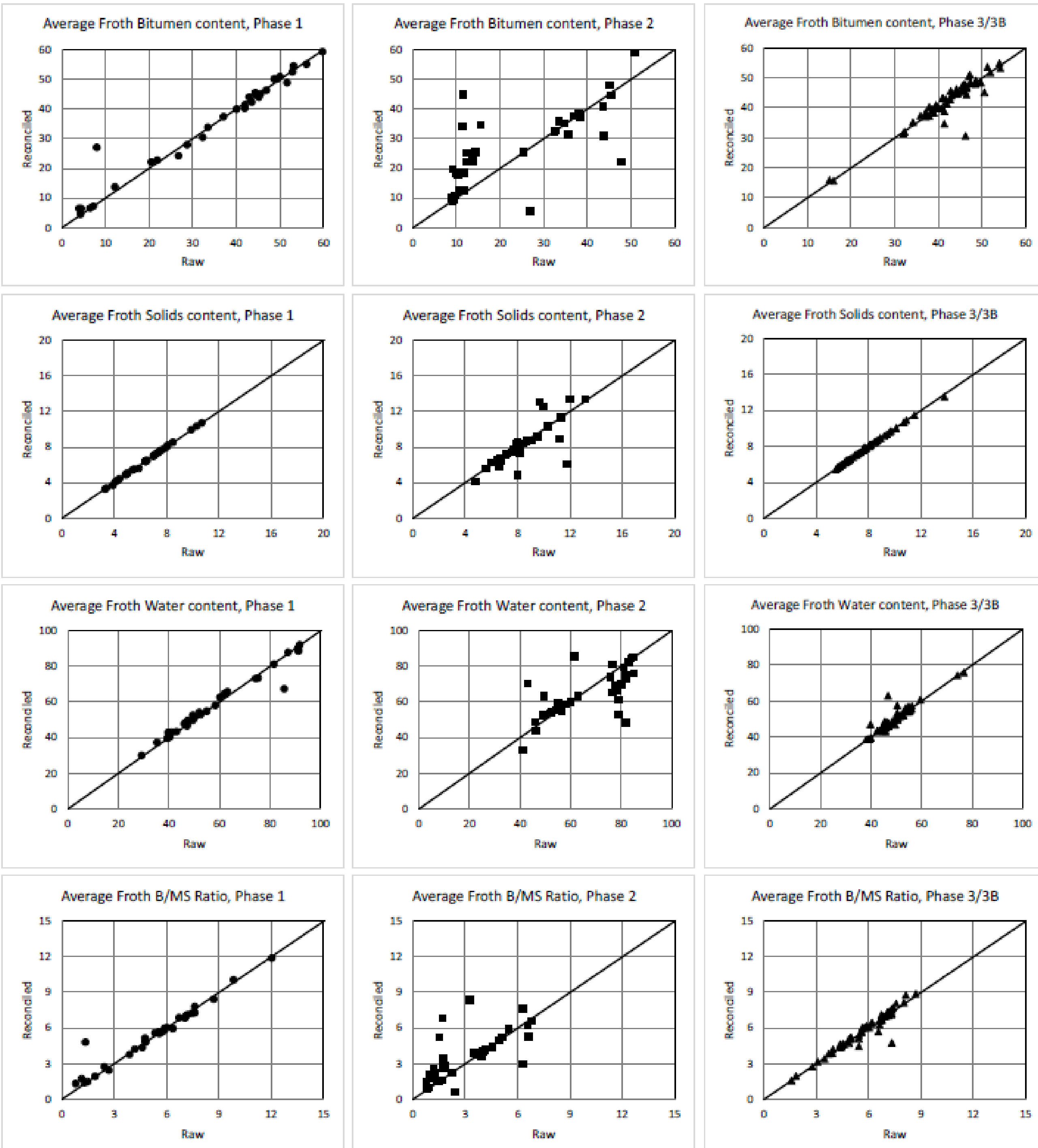


Figure 21: Comparison between raw and reconciled froth composition

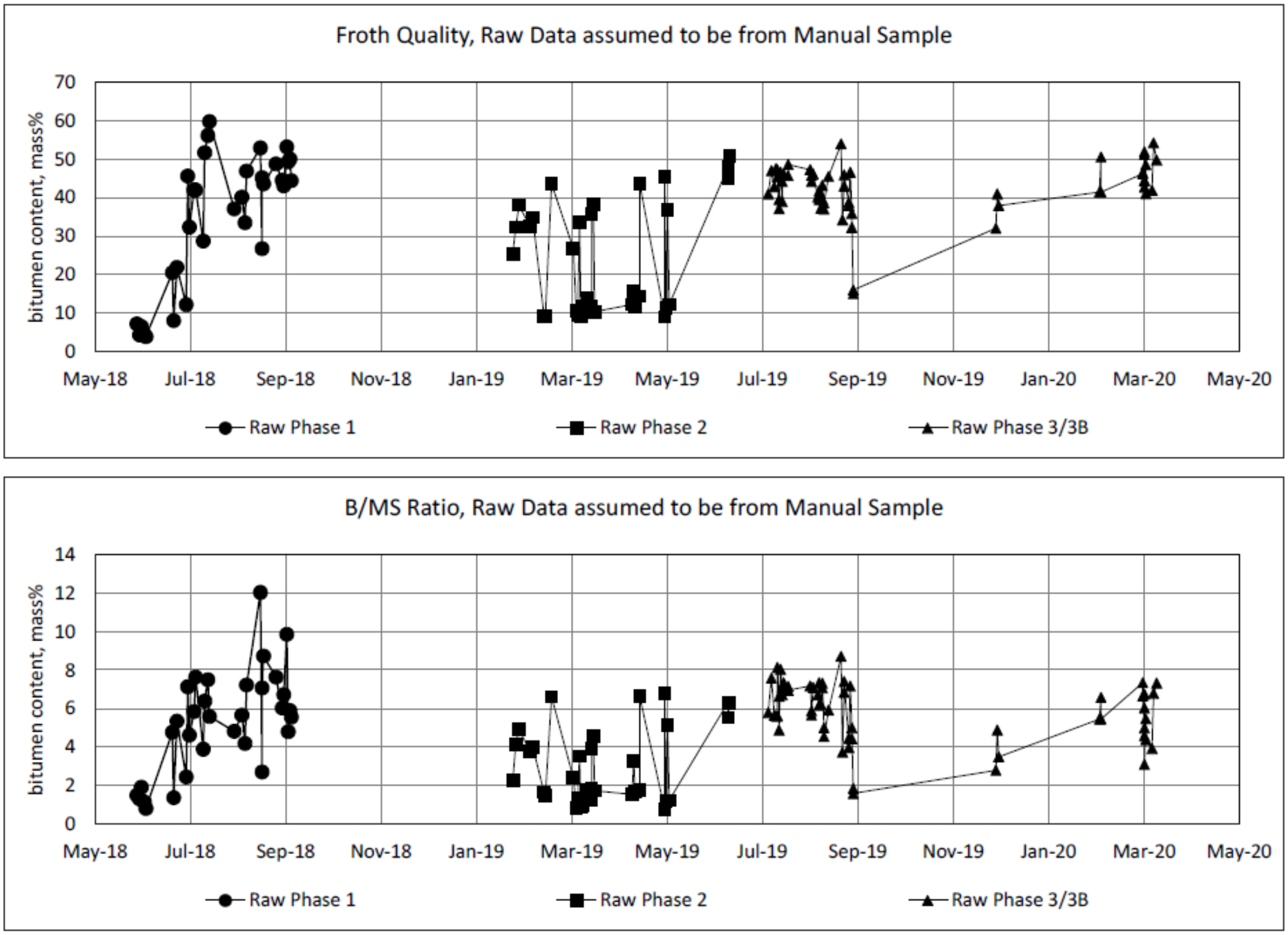


Figure 22: Raw undiluted froth composition shown as froth quality (a) and B/MS ratio (b)

In general, froth quality increase and the variability in froth quality decreased in Phase 3 as shown in the box and whiskers plot (Figure 23).

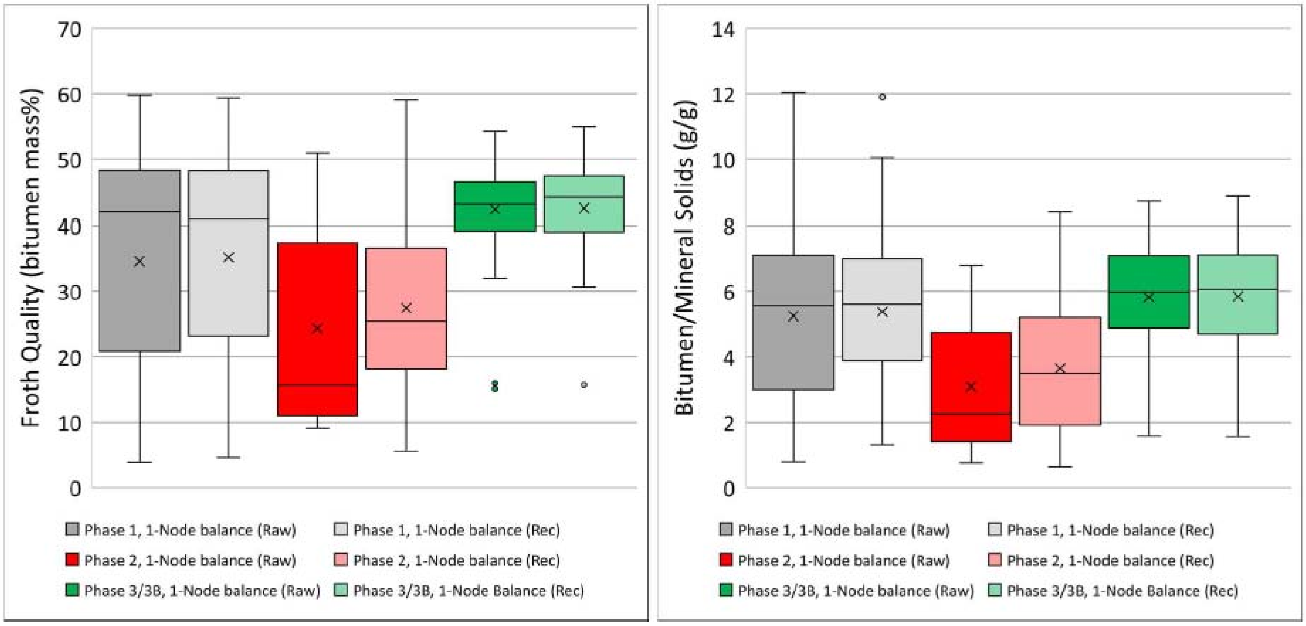


Figure 23: Box and whiskers plots of raw and reconciled froth quality and B/MS ratio for Phase 1, 2, 3/3B

Table 5 summarizes the raw and 1-Node reconciled data.

Table 5: Raw and reconciled undiluted froth quality during Phase 3/3B, data used in 1-Node balances

	Froth Quality (wt% bitumen)		B/MS Ratio	
	Raw	1-Node Reconciled	Raw	1-Node Reconciled
Numerical average	42.3	42.5	5.8	5.8

As ore grade increases, froth quality generally also increases, as shown in Figure 24, Figure 25, and Figure 26. Figure 26 shows occurrences of "low[2]" and "high" froth quality and that the occurrences of low froth quality decrease as ore grade increases, and vice versa. Higher froth quality was achieved in Phase 3/3B with fewer instances of low froth quality.

[2] "Low" quality is defined as froth with <35 wt% bitumen, and "high" quality is froth with >45 wt% bitumen.

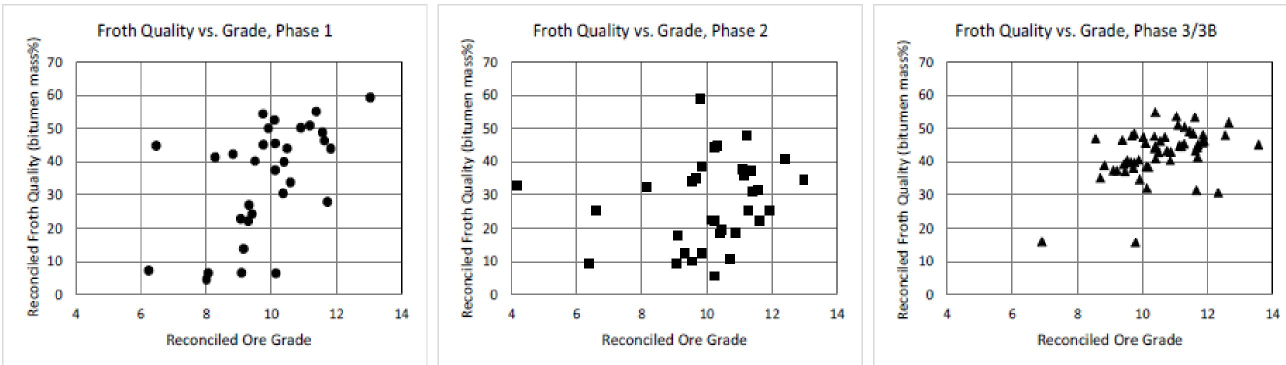


Figure 24: Froth quality as a function of ore grade. All values are reconciled from the 1-Node balance

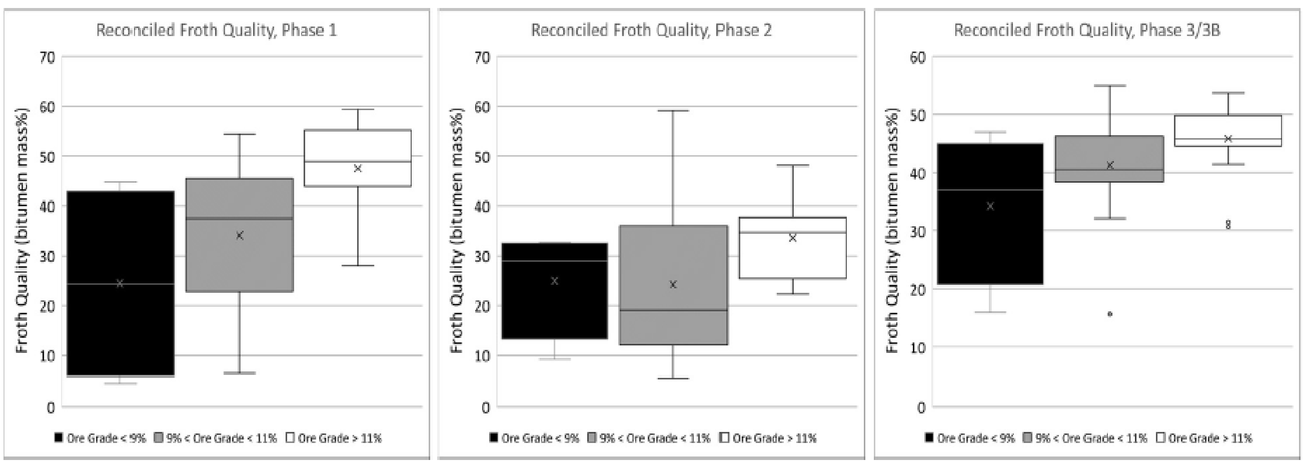


Figure 25: Box and whisker plots of reconciled froth quality at three ore grades (bins) for each Phase.

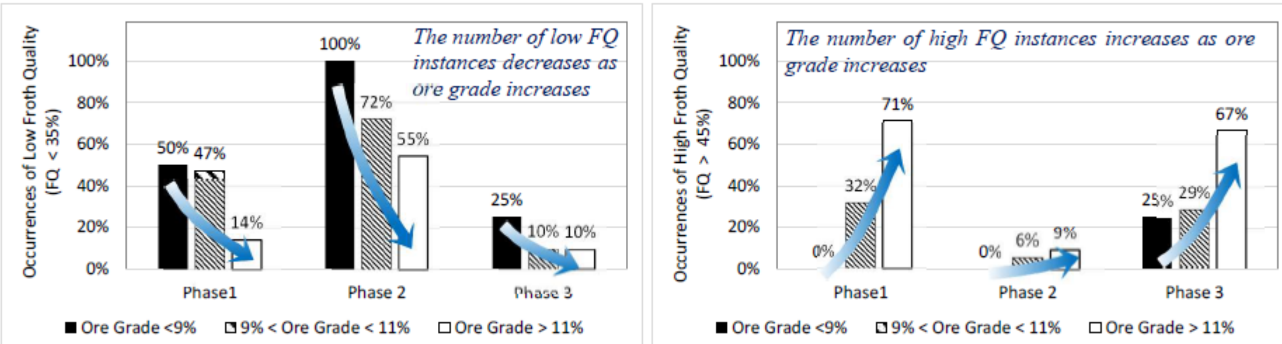


Figure 26: Occurrences of high (FQ > 45%) and low (FQ < 35%) froth quality (FQ) for three bins of ore grade (all values are reconciled form the 1-Node balance)

As froth samples are key performance indicators for recovery and froth quality, any future pilot work should ensure that the samples are representative, attempt to maximize froth quality (>45 wt% bitumen), and ensure the froth concentrator is trialed to verify that it is capable of sufficiently upgrading the froth to a value suitable for the froth treatment plant. A summary for Phase 3/3B is given in Table 6.

Table 6: Reconciled froth quality for three bins of ore grade in Phase 3/3B

	Reconciled Froth Quality		
	Ore Grade <9%	9%< Ore Grade <11%	Ore Grade >11%
Numerical average	34.3	41.3	45.9

For ore grades above 9%, froth quality is typically 40-50%. There is no discernable trend between ore quality and fines content of the froth solids.

10.4 Tailings Solids

The average raw mass flow rate of whole tailings (combined tailings that may include material from the belt filter, screens, and centrifuge cake depending on the Phase) is shown in Figure 27. After the 1-Node balance it was observed that the reconciled mass flow rate of whole tailings was consistently lower than the raw value (Figure 28).

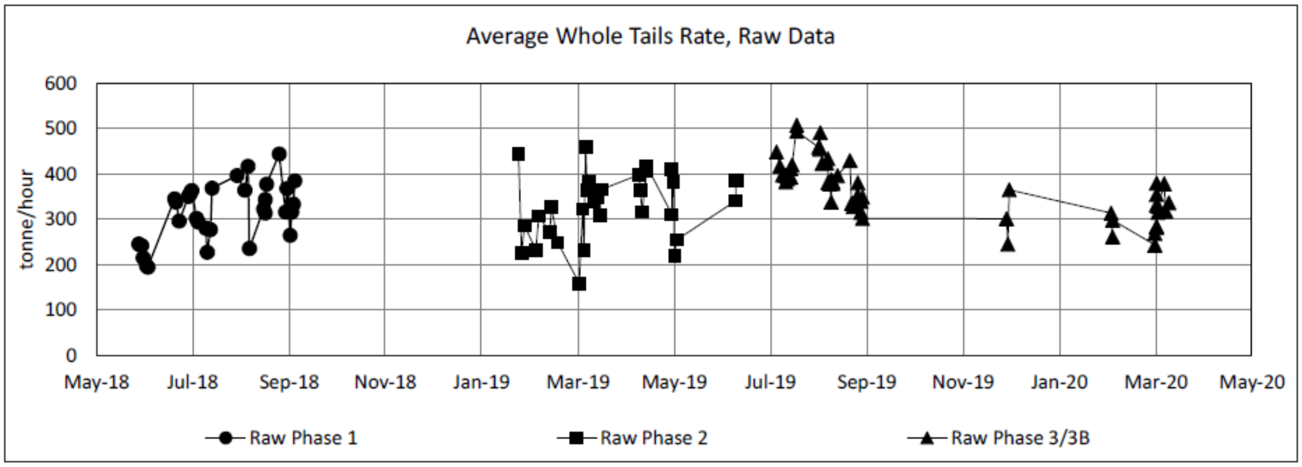


Figure 27: Raw whole tails tonnage

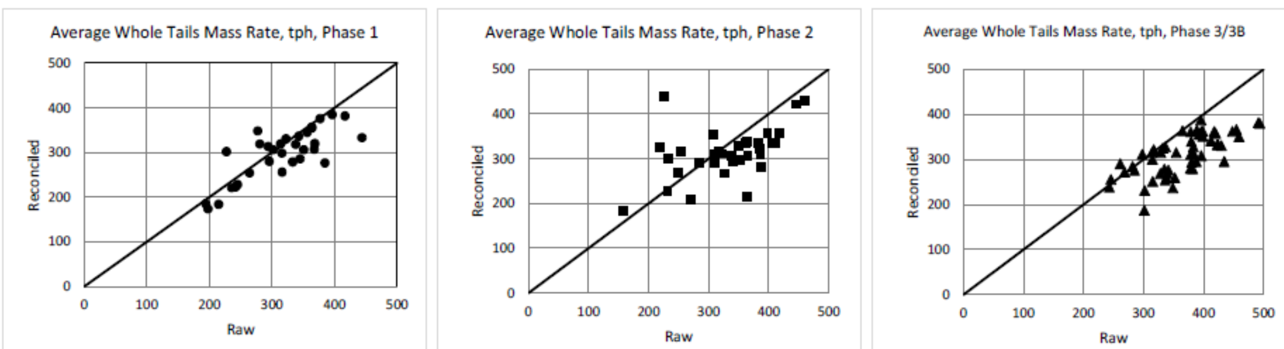
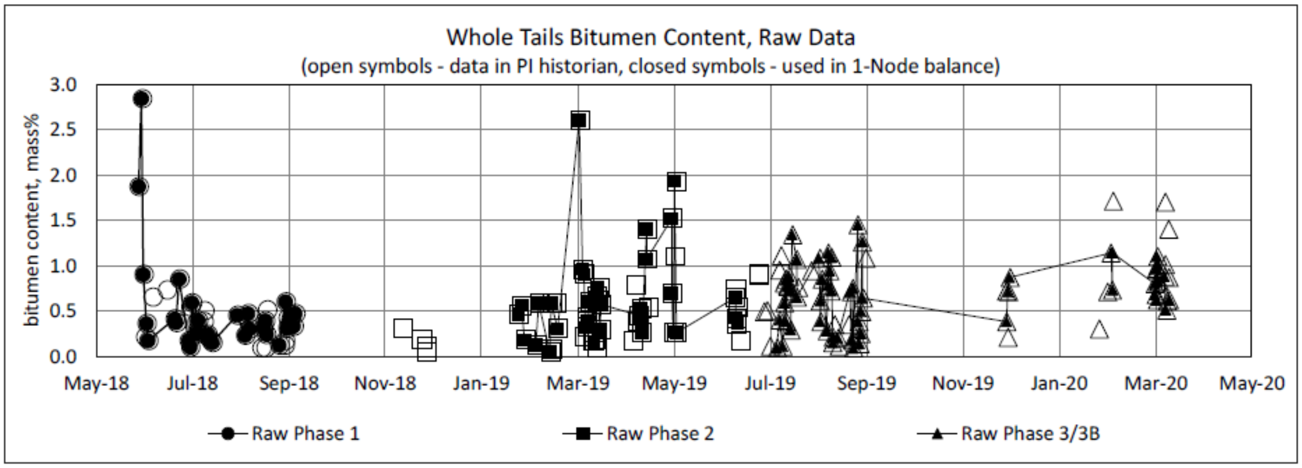


Figure 28: Comparison between raw and reconciled whole tails tonnage

Bitumen content in whole tailings varied from 0.1 to over 1 wt% (Figure 29a) while the water content varied from 10 to 25 wt% (Figure 29b). Comparisons of the raw and 1-Node reconciled data (Figure 30) show little bias between the data sets and therefore had good alignment.



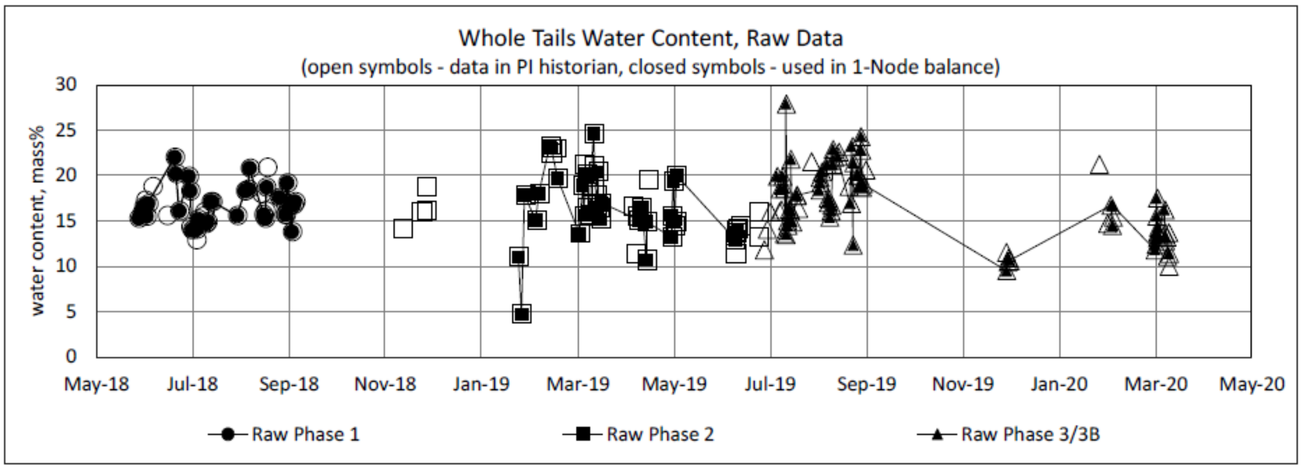


Figure 29: Raw whole tails composition, bitumen content (a), and water content (b)

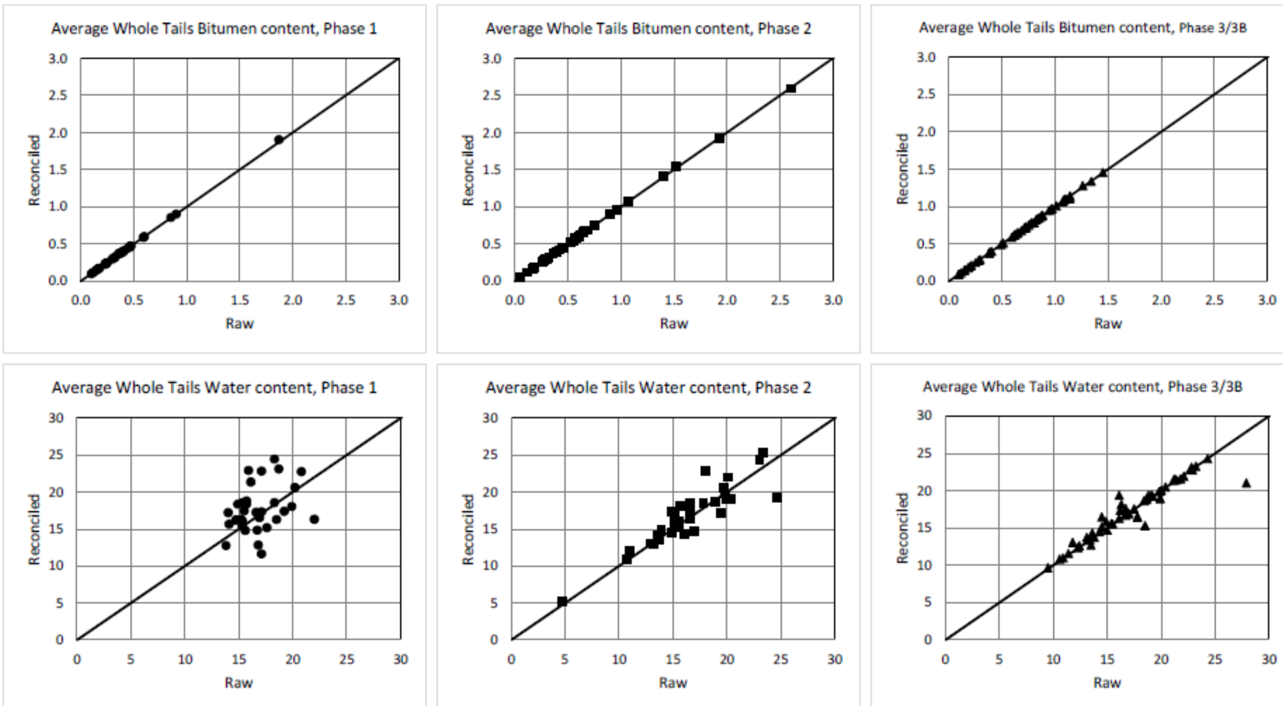


Figure 30: Comparison between raw and reconciled whole tails composition

The box and whiskers plots (Figure 31) show that the bitumen content, water content, and SFR of the whole tailings had a wider spread in Phase 3/3B, compared to Phases 1 and 2. It also shows that the bias in tailings tonnage measurement is driving the adjustments in total whole tailings tonnage. Raw and reconciled whole tailings composition (bitumen, water) during Phase 3/3B is compared in Table 7.

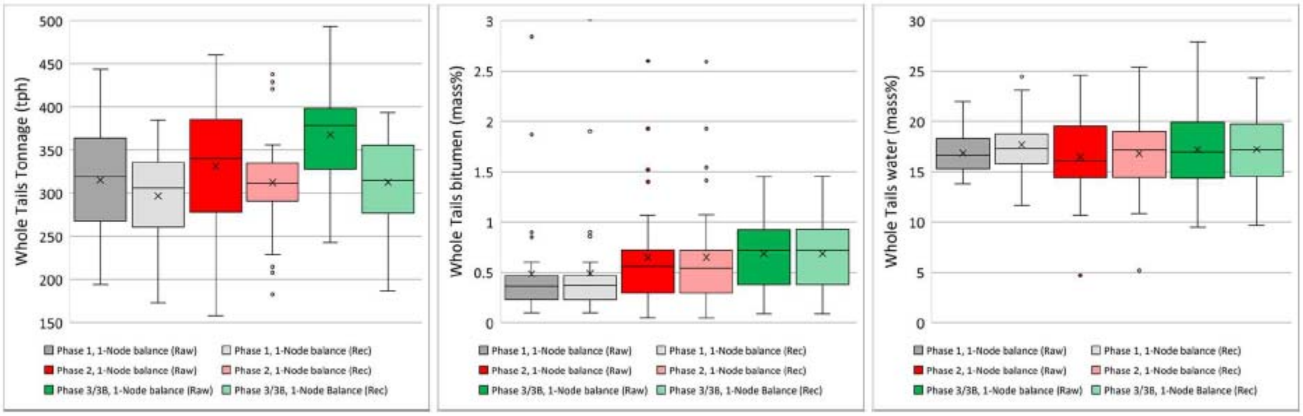


Figure 31: Box and whiskers plots of raw and reconciled whole tails tonnage and composition (bitumen and water content) for Phases 1, 2, and 3/3B.

Table 7 Raw and reconciled whole tails composition during Phase 3/3B, data used in 1-Node balances

	Bitumen Content (wt% bitumen)		Water Content (wt% water)		SFR
	Raw	1-Node Reconciled	Raw	1-Node Reconciled	Raw
Numerical average	0.69	0.69	17.2	14.2	6.0

Tailings water content has a strong impact on geotechnical stability of IPEP whole tailings. It should be re-stated that the tailing treatment process of IPEP 500 changed substantially between Phases.

Figure 32 shows reconciled ore grade versus whole tailings water and bitumen content. Figure 33 and Figure 34[3] show no trends between ore grade and tailings water content in Phase 1 and 2, though some trend is observed in Phase 3/3B.

[3] Low water content is defined as <15 wt% and high water content is defined as >20 wt%. It should be noted that these values were chosen for illustrative purposes and do not imply these are equivalent to geotechnically stable or unstable tailings.

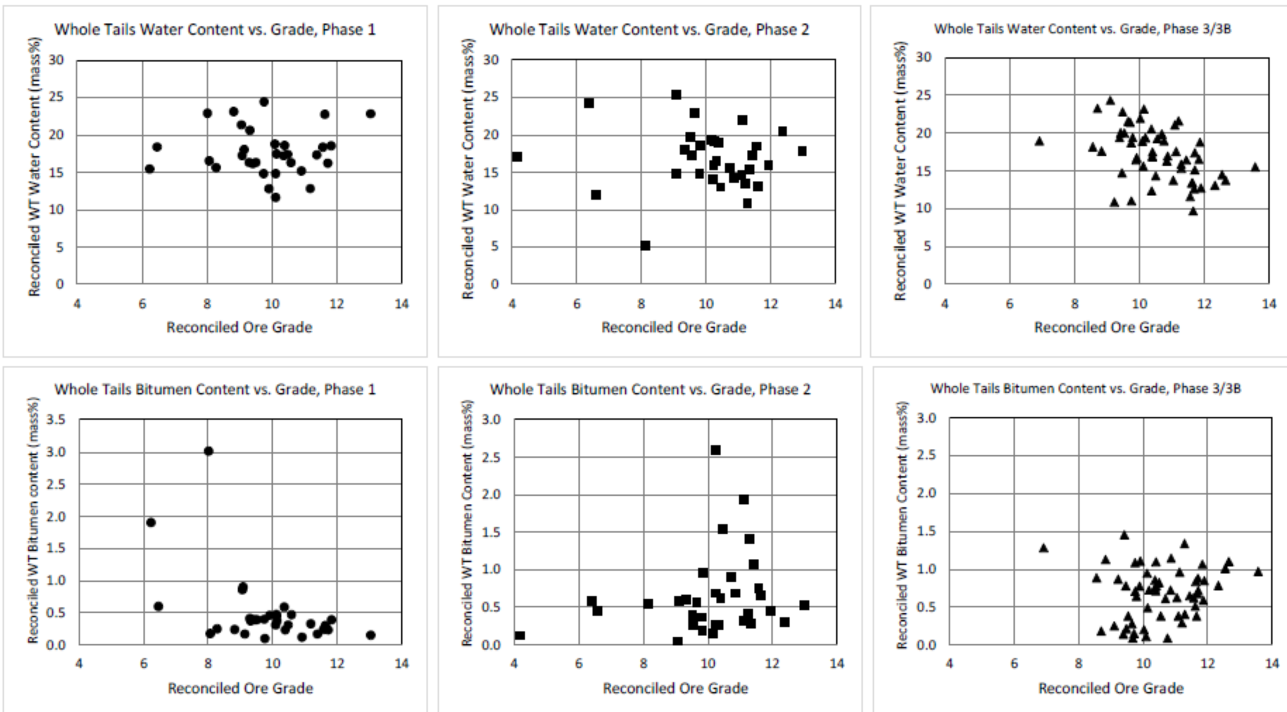


Figure 32: Whole tails water and bitumen content as a function of ore grade (all values are reconciled from the 1-Node balance)

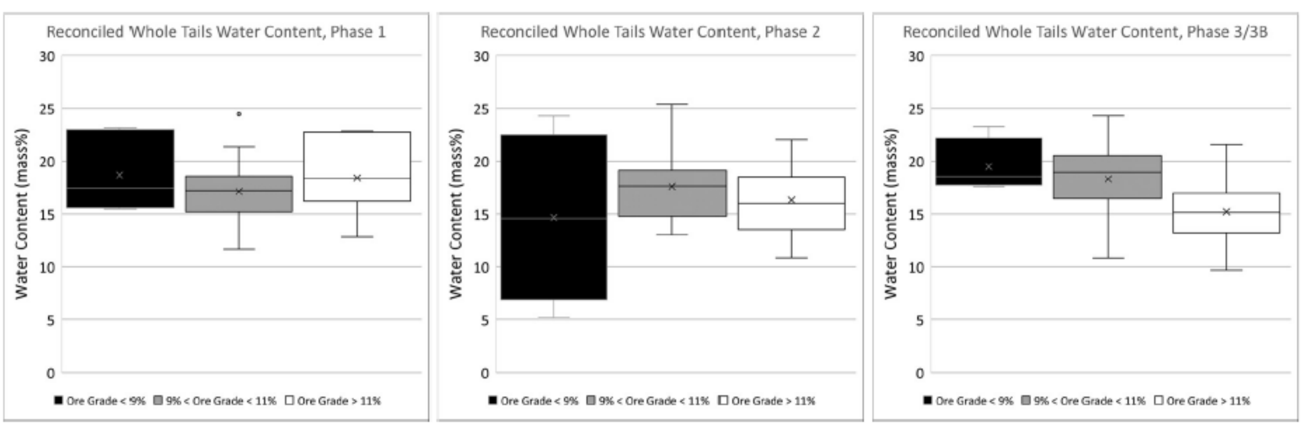


Figure 33: Box and whisker plots of reconciled whole tails water content at three ore grades (bins) for each Phase

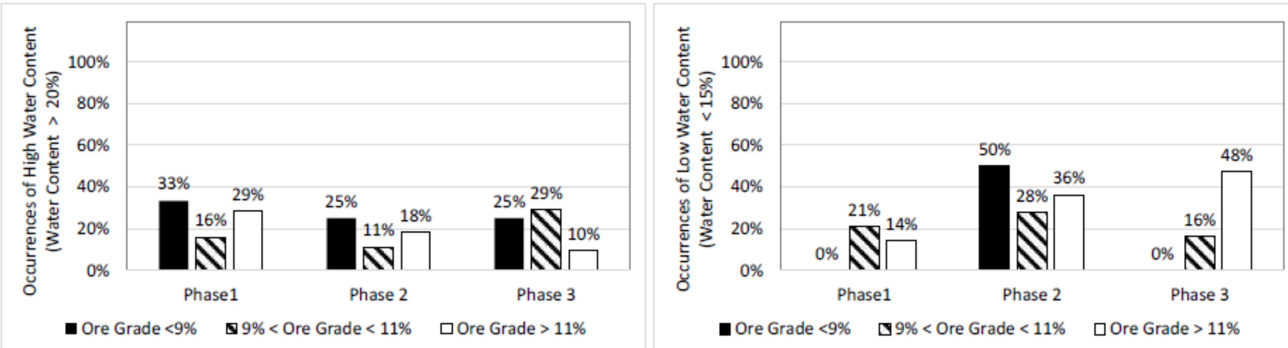


Figure 34: Occurrences of high (water > 20%) and low (water < 15%) whole tails water content for three bins of ore grade (all values are reconciled form the 1-Node balance)

Figure 33 and Figure 35 show that the tailings water content ranges from 15-18% and decreases as grade increases in Phase 3/3B.

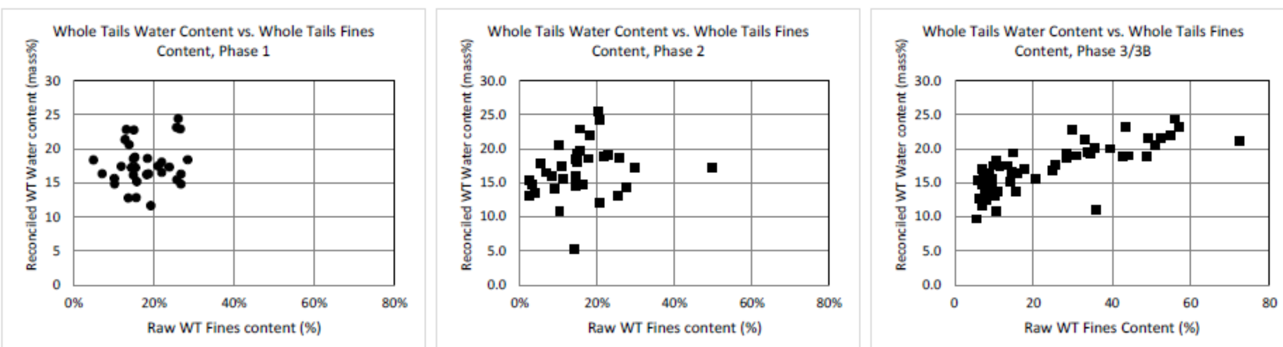


Figure 35: Whole tails water content (reconciled) as a function of whole tails fines content (raw)

Table 8 summarized the relevant parameters for Phase 3/3B.

Table 8: Reconciled whole tailings water content for three bins of ore grade

	Reconciled Whole Tailings Water Content (wt% water)		
	Ore Grade <9%	9%< Ore Grade <11%	Ore Grade >11%
Numerical average	19.5	18.3	15.2

10.5 Hot Process Water (HPW)

HPW is added to the ore to create a slurry at a temperature around 50°C. HPW was not sampled, but is the same water used in the main plant and generally has a solids content <0.5 wt% and only trace amount of bitumen. HPW and HPW/ore ratio are important parameters to determine the amount of HPW used in the plant as well as how IPEP compares to the main plant's HPW/ore ratio.

Figure 36 compares the ratio of HPW usage to ore throughput, which was generally in the range of ~0.4-0.8 (an overall range of 0.3-1.5). In comparison, the existing extraction process at Horizon operates in the range of 0.5-0.6.

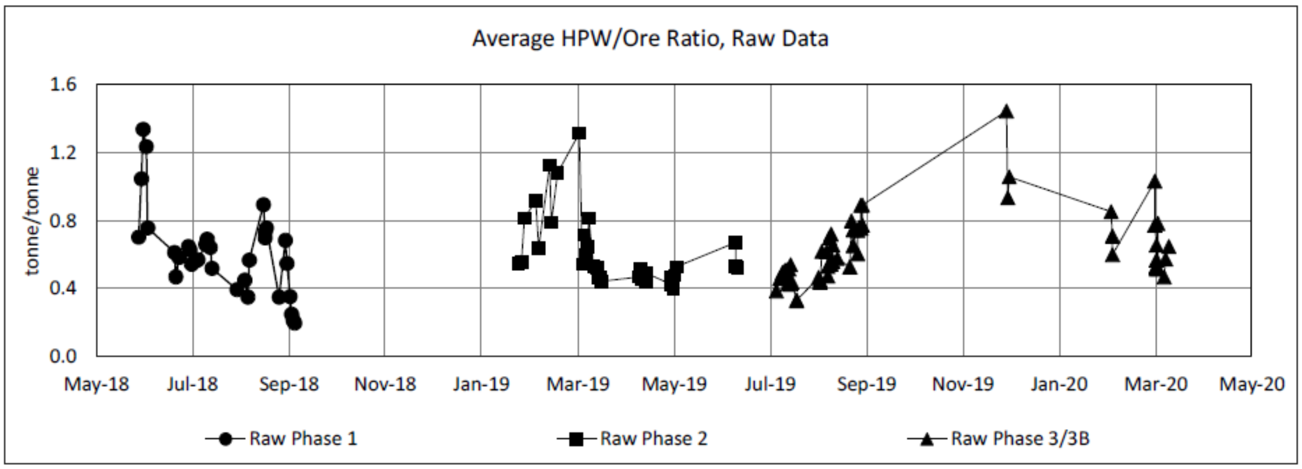


Figure 36: Raw HPW/Ore ratio

Comparing raw and reconciled data (1-Node), there is a slight bias to reconcile HPW usage lower. Combined with the knowledge there was also a bias to reconcile ore tonnage higher, the reconciled HPW/ore ratio is lower than the raw value. These trends are shown in Figure 37.

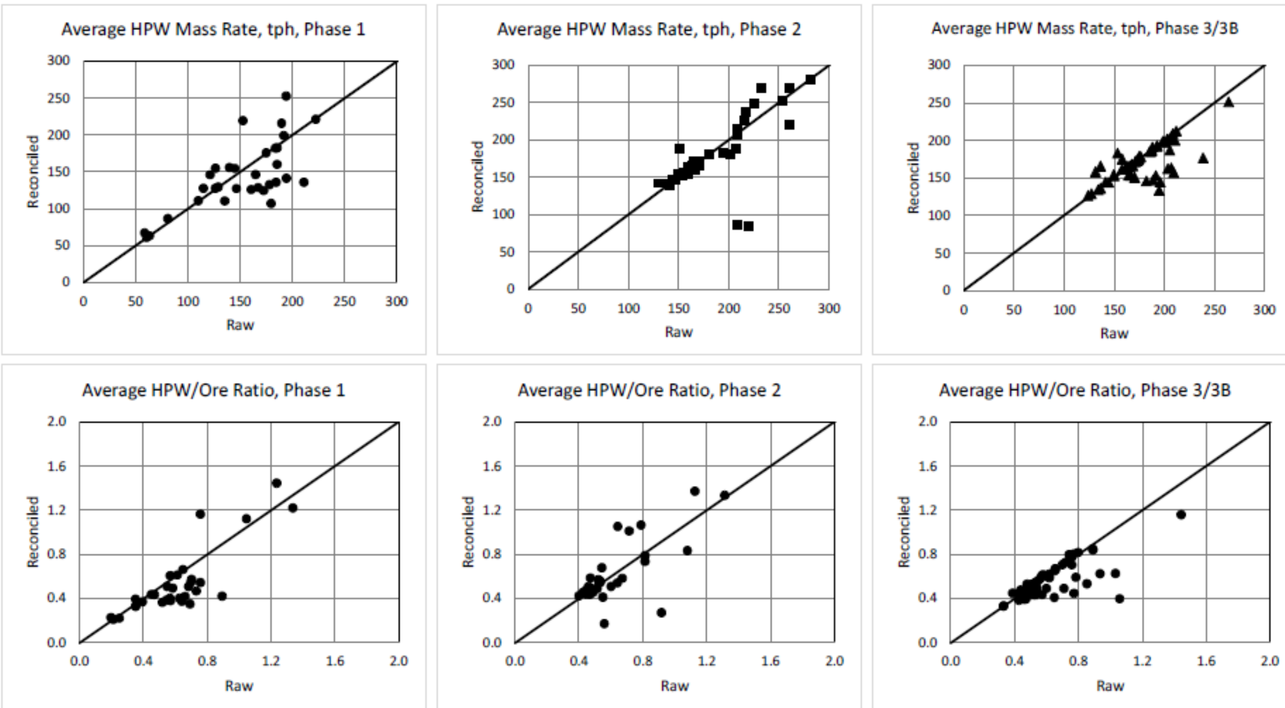


Figure 37: Comparison between raw and reconciled HPW tonnage and HPW/Ore ratio

Typically, low ore grades are associated with high fines and higher HPW usage (either for mechanical operating reasons and/or to achieve an acceptable recovery).Table 9 shows that this trend is also true for IPEP.

Table 9: Reconciled HPW/Ore ratio for three bins of ore grade in Phase 3/3B

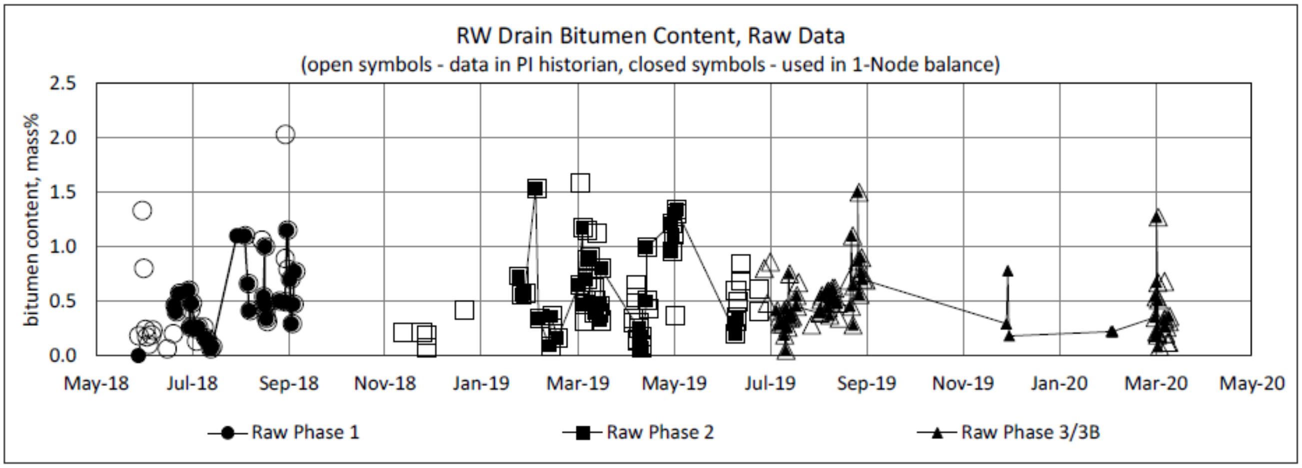
	Reconciled HPW/Ore Ratio		
	Ore Grade <9%	9%< Ore Grade <11%	Ore Grade >11%
Numerical average	0.66	0.59	0.52

10.6 Recycle Water

Recycle water was added back to the process in various places in the plant (including sizer, coarse and fine washer screws, dewatering screen under pan, etc.) and excess water was removed from the process via the froth line. In the recycle water, the important indicators are bitumen content (represents lost bitumen when the excess water is dumped) and solids content (negatively impacts plant performance).

Figure 38 shows that the bitumen content of the RW varied from 0-1.5 wt% bitumen for all Phases and solids content varied between ~1-8 wt% during Phases 1 and 2. Solids contents as high as 10 wt% was observed during Phase 3. The average values were 0.48 wt% bitumen and 4.49 wt% solids.

In general, as ore grade increased, the quality of the recycle water also increased (less bitumen and solids) as shown in Table 10 and Table 11 (data for Phase 3/3B).



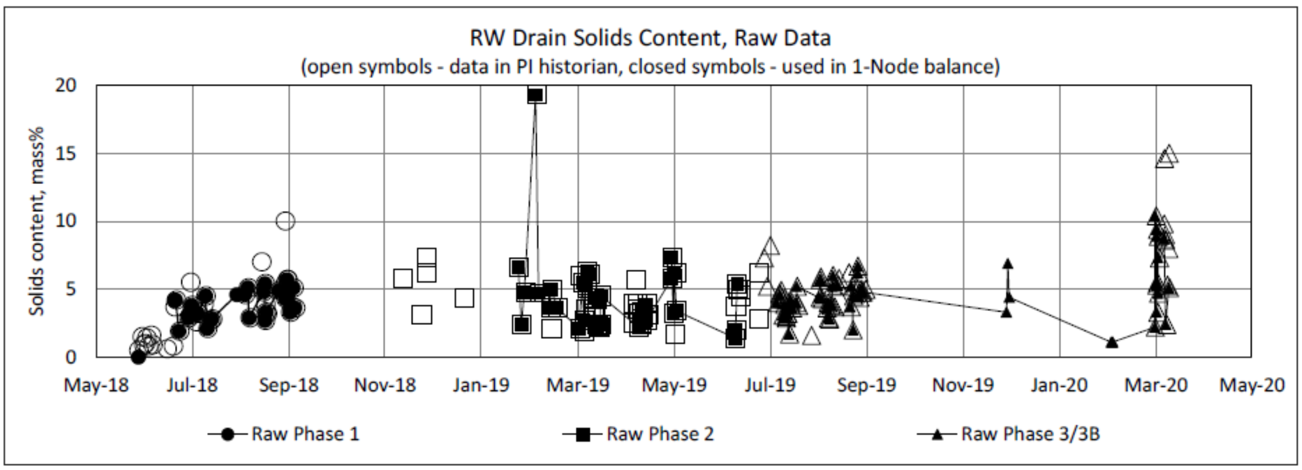


Figure 38: Raw RW drain composition

Table 10: Reconciled RW drain bitumen content for three bins of ore grade in Phase 3/3B

	Reconciled RW Bitumen Content (wt% bitumen)		
	Ore Grade <9%	9%< Ore Grade <11%	Ore Grade >11%
Numerical average	0.69	0.55	0.33

Table 11: Reconciled RW drain solids content for three bins of ore grade in Phase 3/3B

	Reconciled RW Solids Content (wt% solids)		
	Ore Grade <9%	9%< Ore Grade <11%	Ore Grade >11%
Numerical average	3.2	4.5	4.8

Further piloting to understand the expected recycle water quality and its impact on overall IPEP performance is recommended. Lengthy run times are needed to understand if the quality of the recycle water has reached a plateau or if additional solids will build up in the circuit.

10.7 Coarse Washer Screw Overflow

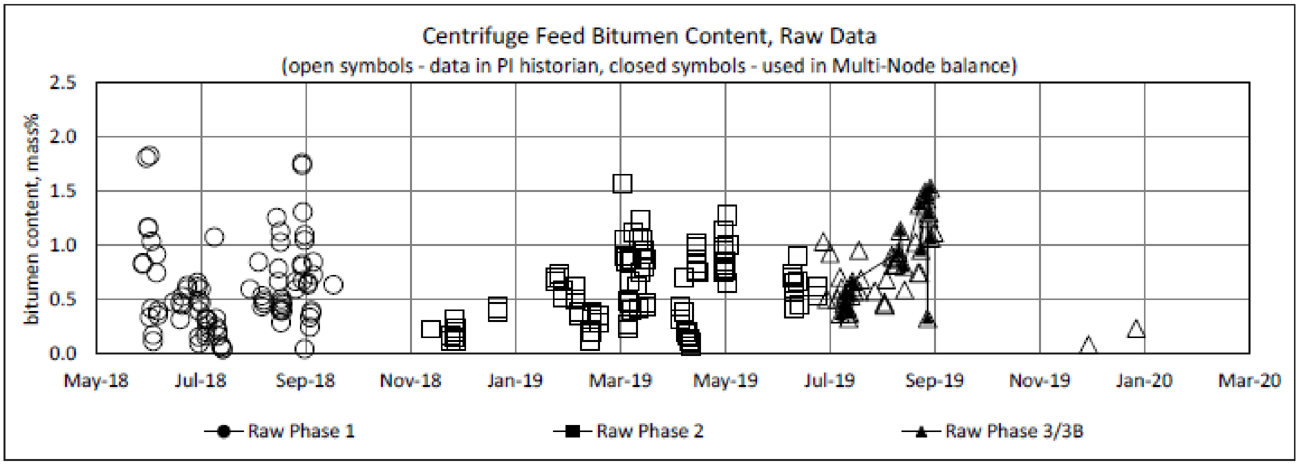
Material leaving the coarse washer screw O/F was collected in a pumpbox (PB-3Y02) and sampled after the pumpbox pump (G-3Y08). In general, the bitumen content varied from ~1 to 6 wt% while the solids content varied from ~10 to 50 wt%.

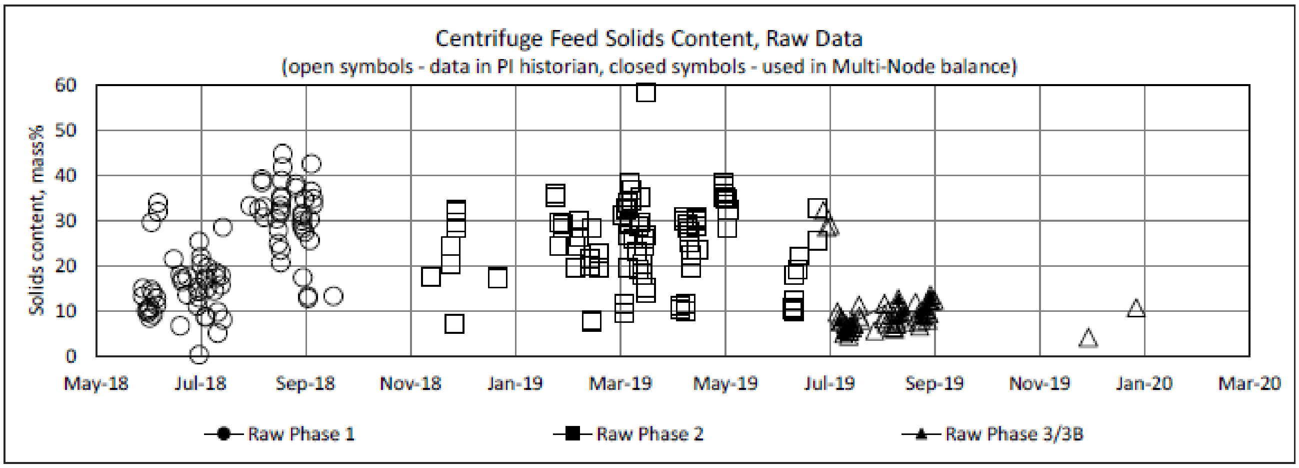
10.8 Centrifuges

The centrifuge feed consisted of FTC2 U/F in Phase 1/2/3 and the thickener U/F in Phase 3B. The composition of the centrifuge feed is shown in Figure 39. The decrease in solids content and increase in fines content in Phase 3B is due to the removal of coarse solids in the cyclones installed in Phase 3B (between Flotation Cell 1 and 2).

Test Centrate was collected just prior to the reclaim water tank and the composition of this stream was ~0-1.5 wt% bitumen and ~2-10% solids. Over 95% of the bitumen in the centrifuge feed reported to the centrate, however the high solids content of this stream would tend to indicate poor operation/classification by the centrifuges.

Test Centrifuge cake was collected on the cake conveyor and the composition of the cake was 0.1-1 wt% bitumen, while solids varied from ~70 to 75 wt%. The sample data was almost exclusively from Phase 3/3B.





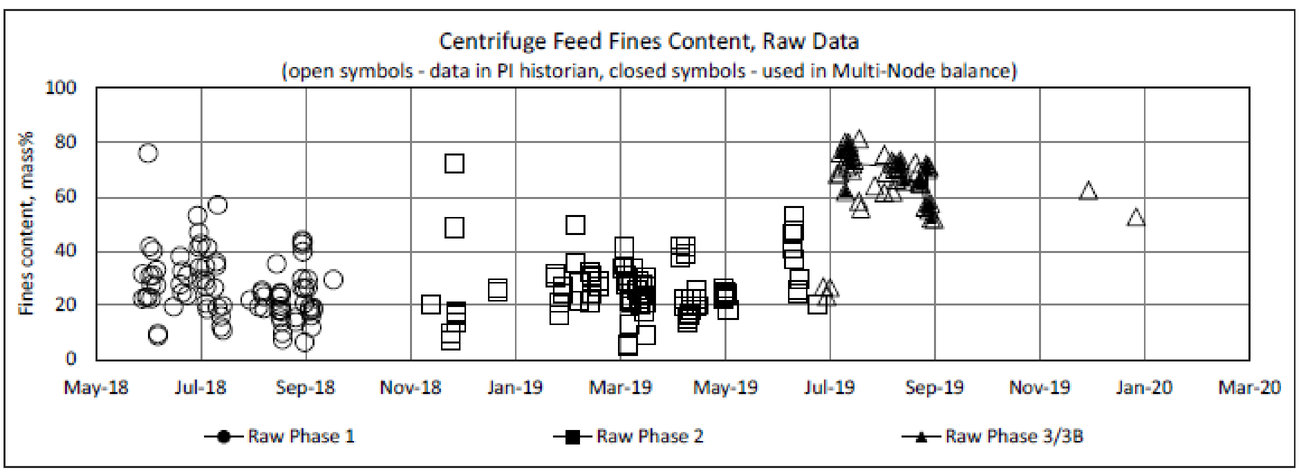


Figure 39: Raw centrifuge feed composition

10.9 Cyclones and Belt Filter Discharge

Cyclones were added in Phase 3 and the composition of the cyclone U/F varied between 0.2 and 1 wt% bitumen and solids from 70 to 75 wt%. As expected, the U/F was a low fines stream (4-10 wt%).

The impact of alum dosage on the belt filter was not investigated, and it is recommended that dosing and observations be collected and analyzed to assist with interpretations of the belt filter performance.

The solids content of the belt filter ranged from 75-85 wt% solids.

10.10 Conclusions from Data Analysis

1. BILMAT was used to create a single node (1-Node) mass balance. The raw data was compared to the reconciled data.
2. Gaps exist in the data due to sampling difficulties, time (both pilot run time and sample round time), and lack of instruments and/or issues with instrument calibration. The data gaps make it difficult to make conclusions on the effectiveness of individual pieces of equipment.
3. A limited number of total data sets exist, particularly with low grade ore. Due to the availability of data sets, the reconciled ore data looked at ore with 9-11 wt% bitumen.
4. Ore throughput ranged from 200-400 t/h for the entire pilot run, though tended to be higher in Phase 3 (300-325 t/h). The ore grade ranged from 6-15 wt% bitumen and the fines content from <5 wt% to >40 wt%.
5. Average recovery for Fall Average grade ore was 90.7%. Recovery in IPEP should be compared to OPP + Extraction in the main plant. Since the AER Directive 082 recovery curve includes Froth treatment, IPEP recovery can be multiplied by ~0.98 (for froth qualities >50 wt%) to get an estimate of the total recovery to compare against the AER curve. As expected, as ore grade increases, recovery also increases and the frequency of low recovery events decreases. Reconciled recovery showed a bias of being 1.5% higher than the raw values.
6. There were significant challenges in pumping and measuring the froth production at IPEP. A large volume of water was added to the froth stream to pump it due to the viscosity and high air content of the undiluted froth. In Phase 3/3B froth quality tended to be higher and less variable than in the earlier Phases. As expected, as ore grade increased so did froth quality, however the overall bitumen content of the froth was 42.3% (for ore grades of 9-11 wt% bitumen) compared to the target of 55 wt%. The bitumen/mineral solids ratio was 5.8, corresponding to 7.29% solids in the froth. The froth concentrator was installed but there was insufficient time to test this piece of equipment.
7. The tailings sand had a bitumen content of 0.1-1 wt% and a solids content of 75-80 wt%. In Phase 3/3B, the water content of the tailings sand decreased as grade increased. It should be noted that the whole tailings sands samples do not appear to be representative of the stream (poor match between raw and reconciled data) and tended to reconcile lower than the raw values. Additional sampling to ensure samples are representative of the combined stream (centrifuge cake plus belt filter cake) is recommended.
8. The recycle water had a typical solids content of 1-8 wt% but more data is recommended. Since there were a limited number of longer run times, the impact of the recycle water (as a recirculating load) is not well understood.
9. In Phase 3B, the composition of the coarse washer screw O/F (to the flotation circuit) was 2.5-6 wt% bitumen, 20-45 wt% solids, and the solids were 10-30 wt% fines. Overall this suggests that a significant amount of the coarse solids are entering the flotation circuit instead of directly entering the tailings circuit. Again, additional sampling is recommended.
10. There is poor alignment of the centrifuge data and additional sampling is recommended, particularly around the centrate. As expected bitumen tended to travel with the water to the centrate. The cake contained a consistent 72-75 wt% solids, however the mass balancing reported that only 40-60% of the solids in the

feed tended to leave with the cake. This does not align with the expected performance of the centrifuges and therefore it is recommended that additional work be done on the centrifuge circuit to verify the result.

11. The cyclone u/f contained 70-75 wt% solids.. A significant amount (60-80 wt%) of bitumen in the cyclone u/f stayed with the solids on the belt filter.
12. The belt filter performance (cake solids) tended to increase with ore grade, and the cake averaged 75-95 wt% solids. No data is available to determine the impact of alum dosage on belt filter performance.

11 Recommendations

There are several remaining IPEP development objectives, with the froth cleaning trials being considered significant. These objectives are desirable to confirm and otherwise prove prior to commercial deployment of IPEP in a production setting. Some of these are remaining due to the early deferral of the IPEP 500 pilot and some are outcomes of the IPEP 500 pilot work. Others are items that are only possible to be completed with the development and longer-term operation of a commercial demonstration plant. The remaining objectives are outlined in the following sections.

11.1 Froth Cleaning

The IPEP 500 pilot demonstrated that the froth residence time was insufficient to reach the desired froth quality of 55 wt% bitumen. The vessel height and associated froth depth are less than the current primary separation cell (PSC) process vessel. In addition, improving froth deration ahead of pumping back to froth treatment is desirable. Piloting a concept based on experience with the IPEP 100 development work is planned as part of the next phase of development. This concept will use screw technology to both clean, heat, and de-aerate the froth in a simple and compact space while also improving the control scheme for the flash flotation vessel. The objective will be to determine sizing and operational parameters in addition to proving the process capability of the equipment.

11.2 Low Grade Recovery Data

While every effort was made to run the lowest grade ore available there is a gap in the mass balanced runs for ore with less than 8 wt% bitumen. Since plant performance followed the expected recovery and froth quality decline with grade that is typical in oil sands, it is desirable to process and collect detailed sampling data on ores in the range of 6-8 wt% bitumen. This would be a specific objective of any future pilot demonstration.

11.3 Dry Ore Direct Feed

Direct dry ore feed to the washer screws was done in the IPEP 100 development with good success but has not been corroborated in the larger IPEP 500 pilot. It is expected to offer improvement in operation complexity, reliability, and water balance, and for completeness is included as an objective in the next stage of development. The objective will be to determine that the expected benefits are understood and that if unanticipated issues arise, what mitigations can be implemented.

11.4 Centrifuge Optimization / Alternatives

Operation of the centrifuges in the IPEP 500 pilot was mainly performed by the contractor operators. During the pilot, a smaller centrifuge was to be trialed and operated by Canadian Natural operators to gain experience and operational knowledge of this equipment. The early shutdown of the pilot interrupted this and so it remains an objective to get direct operating experience with centrifuges. In addition there is potential to develop alternative equipment for dewatering thickened fines. The belt filter press is a belt dewatering device based on successive rollers squeezing the material between two filter belts. This equipment could be a less expensive and less GHG intensive dewatering step and would be incorporated into the demonstration pilot scope.

11.5 Alternate Chemicals

One of the incomplete objectives of the IPEP 500 pilot was to trial alternatives to Alum, and it was found that polymer flocculants and lime both have potential. Testing both of these options would be part of the pilot demonstration scope with the objective of finding a less expensive option or one with synergistic and tailings quality enhancing properties in the case of lime.

11.6 Reliability

One of the key targets of IPEP 500 was achieving extended run times and ultimately 24 h continuous operation. Run times did improve over the course of the pilot's improvements, but did not reach the target. Per Section 8 of this report, the primary cause of pilot shutdowns was the ore feed equipment, specifically the conveyors (35.7%) and the crushers (25.0%). This equipment also contributed to a combined 42.1% of downtime. As this equipment is well-known technology for oil sands, it is anticipated that the reliability of this equipment can be improved significantly to decrease the frequency and duration of shutdowns, and achieve continuous pilot operation. Discussions on operability and reliability issues for these and other equipment are discussed in Section 7- IPEP Unit Operations.

In addition, developing a future commercial demonstration module would enable testing the very same equipment that would be on the commercial module. This will provide true reliability data and opportunity with an extended run time to optimize materials and fine tune designs to maximize reliability and minimize cost. If completed prior to commercial deployment, this particular objective can have an outsized impact on commercial economics. For example, a 10% improvement in reliability can eliminate 5-10% of the capital cost of the commercial deployment.

11.7 Stackable Tailings Handling/Dump Design

Long-term supply of stackable tailings allows for experimentation with different deposit and dump designs, which take several months to a year to complete and analyze. Running the demonstration pilot over 2-3 years allows us to learn and improve in this area, potentially simplifying the commercial bulk material handling design and cost.

11.8 Sizer Tooth Development

Nearly 50% of the estimated maintenance cost is in sizer teeth. Significant gains can be made by applying known techniques and materials to reduce this cost by half. The wear period for the teeth is in the order of months, so it takes an extended run time to work through the necessary iterations.

11.9 Module Relocation

The relocation of the IPEP module is one of the most novel and integral aspects of the concept. Testing this with a single module ahead of engineering and constructing the full commercial deployment is a significant objective to minimize risk and also has the potential for cost mitigation. Investing in a pilot demonstration module and building it and then relocating it as planned in the commercial scheme will provide significant confidence in this aspect of the design.

11.10 Module Capital Cost Certainty

By actually procuring and constructing a commercial demonstration module the level 1 cost and schedule data will be available for economics ahead of a commercial deployment. This will greatly improve the confidence in the estimates and schedule.

11.11 Operating Cost Certainty

A pilot demonstration will have the design elements, reliability, and operability that will result in lower operating cost compared to the IPEP 500 pilot operation, and as such will provide meaningful direct cost input that can be used in commercial economics and long range plan (LRP) estimates.

11.12 Comprehensive Sampling and Metering

Although extensive sampling and metering was performed during the pilot operations, the Multi-Node analysis revealed several data collection gaps. If possible, resuming the IPEP 500 program to execute these recommendations would be beneficial, and certainly recommended for a commercial deployment of the technology, in order to enable individual equipment mass balances, and the optimization of vessel sizing and equipment operation. Recommendations as follows:

- Metering
  - Install meters on all water streams.
  - Meters (flowmeters, densitometers, and other instrumentation) and weightometers must be calibrated on a regular basis.
  - The errors for online meters and errors associated with samples (sampling from main line, subsampling for lab, analytical error) must be quantified in order to develop appropriate models for future mass balance reconciliation work.
- Sampling
  - Additional sampling around units where possible (including centrifuges), ensure samples are representative.
  - Recycle water quality should be measured in order to understand its impact on the plant with regards to build up of solids or reaching a plateau in recycle water for extended runs.
  - Key streams that were not sampled or measured in previous Phases such as oversize leaving screens, fine washer screw O/F and U/F, coarse washer screw U/F should be measured.
  - Ensure tailings samples are representative.
  - Measure and sample filtrate streams.
  - Though the samples were indeed managed appropriately for IPEP 500, in a future campaign it is recommended that a dedicated IPEP sample team and management program be in place (collection, storage, onsite vs. offsite handling and analysis, quality assurance / quality control, entry into a robust database).
- Assessment of Data
  - Ensure froth samples are representative, and conduct further studies to explain higher B/MS value compared to Horizon and Albian.
  - Run mass balances more frequently to identify biases as soon as possible.

A rigorous sampling and metering program had been planned for IPEP 500 in Spring 2020 for this purpose, but the pilot concluded prematurely.

12 Greenhouse Gas and Non-GHG Impacts

Global pressure to improve ESG (Environmental, Social, and Governance) metrics for oil production are driving the need to change how mineable oil sands are produced. IPEP has the capability to lower GHGs per barrel of bitumen, reduce environmental impacts particularly around generation of fluid tailings, and speed up reclamation. All of these are desirable in an ESG focused world.

Future regulatory approvals for Horizon and any development of other green field leases are a challenge. IPEP technology can address some of these challenges including tailings, GHGs, and water use, improving the probability of securing the required approvals.

Rising Asset Retirement Obligations (ARO) costs are reflecting the increasing liability of the current tailings processes. Canadian Natural's ARO costs have recently increased due to tailings treatment. IPEP technology has the potential to reduce costs for FFT treatments through substantial elimination of FFT production.

There is no future scenario where lower cost is not desirable. Fundamentally moving material the shortest possible distance (IPEP/IPEP enabled mine design premise) resets the fundamental low cost potential of the process and Mine plan it enables. The reduction in hauling distance results in fewer trucks required for the process as well as a substantion reduction in diesel fuel and resulting emissions. Given the same efforts to drive rigorous continuous improvement in current operations, IPEP should be capable of achieving a lower ultimate minimum operating cost due to these material transport distance reductions.

Substantial electrification of the process when combined with low GHG power generation will allow substantial progress towards net zero GHG production of bitumen.

In regards to IPEP's estimated GHG savings over conventional operations, Table 12 presents the power usage data for Horizon's current operations, along with estimated power requirements for a commercial IPEP South Mine design. Power use measured from the IPEP 500 pilot was about 3.8 kWh/t.

Table 12: Preliminary IPEP Greenhouse Gas Reductions

		kWh/t
Horizon Base Plant		
	Ore Preparation Plants	2.3
	Extraction	1.1
	Tailings	2.6
	Total Base Plant	**6.0**
IPEP – South Mine Scope		
	Process Module	3.4
	Corridor Pumphouses	0.6
	Tailings Conveyors/BMH	0.9
	Total IPEP	**4.9**
Net Reduction in Power / GHGs		**18.3%**

Though the GHG reductions are lower than initially estimated, the addition of the centrifuges and the vacuum belt (large vacuum pump) to the design (versus the screens originally in the process) account for the difference. Note the significant reduction in GHGs relating to tailings handling, further GHG emission reductions are also anticipated as a result of IPEP's impacts on tailings pond mitigation.

13 Scientific Achievements

Patent:

- CA2989477 – In Pit Extraction Process, published June 22, 2018
  - https://patentscope.wipo.int/search/en/detail.jsf?docId=CA222134273&tab=NATIONALBIBLIO

14 Next Steps

As for the prospects of commercial implementation, Canadian Natural is evaluating how the technology can be integrated into existing operations, in whole or in part.

To achieve this, the IPEP process still requires further optimization and refinement to achieve the key performance indicator targets, and fully capture all processing data for full plant design. It is recommended to pursue additional pilot operations to this effect, as noted in sections 10.10 and 11, and achieve the following:

1. Verification of Equipment Design;
2. Process Optimization; and
3. Reliability and Extended Run-Times.

15 Communications Plan

Canadian Natural is committed to communicating environment, social, and governance information to our stakeholders on a regular basis. Every day, we are pushing the boundaries to accelerate technology development and move closer to our emissions targets and, ultimately, our aspirational goal of net zero GHG emissions in the oil sands.

Our roadmap to net zero emissions includes different technologies and processes throughout the production cycle: from designing facilities to avoid emissions in the first place, to reworking existing processes to reduce emissions, to storing and/or converting or utilizing the remaining emissions. The IPEP project is an important part of our technology development work at Canadian Natural.

To date, we have promoted the IPEP project both internally and externally. Highlights of these efforts include:

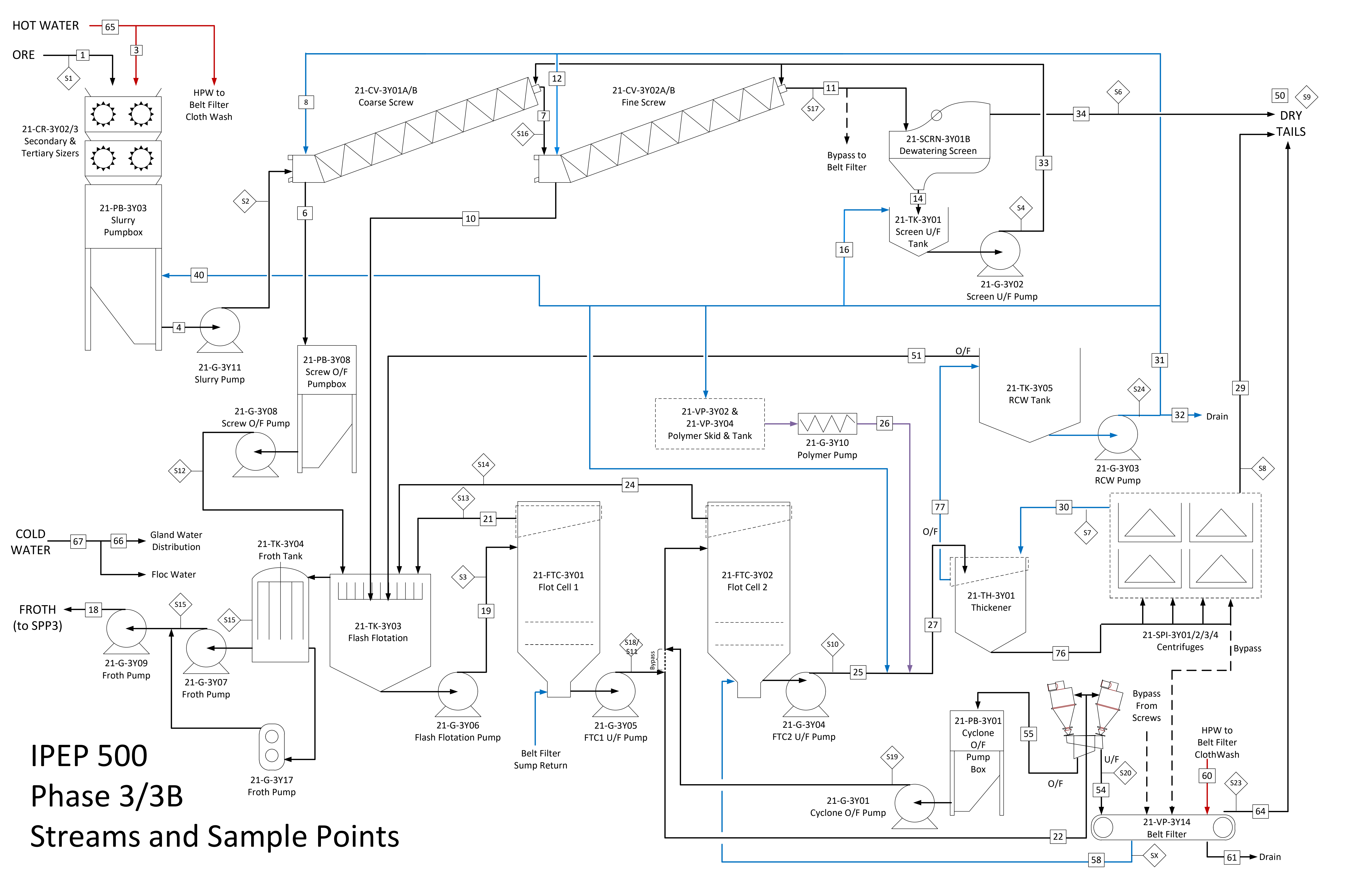
- Press release updates (see Section 13);
- Internal news articles;
- An overview video shared at our company-wide Town Hall and Board of Directors meeting, then hosted on our website and promoted via social media;
- Inclusion in Canadian Natural's annual Technology and Innovation Case Studies booklet profiled on our external website;
- Hosted tours with stakeholders; and
- Inclusion in Canadian Natural's annual Stewardship Report to Stakeholders profiled on our external website.

16 Appendices

Appendix A - IPEP 500 Phase 3B BFD

IPEP 500 PHASE 3B

Appendix B - IPEP 500 Phase 3/3B Streams and Sample Points


HOT WATER
ORE
HPW to
Belt Filter
Cloth Wash
21-CR-3Y02/3
Secondary &
Tertiary Sizers
21-PB-3Y03
Slurry
Pumpbox
21-G-3Y11
Slurry Pump
21-CV-3Y01A/B
Coarse Screw
21-CV-3Y02A/B
Fine Screw
Bypass to
Belt Filter
21-SCRN-3Y01B
Dewatering Screen
21-TK-3Y01
Screen U/F
Tank
21-G-3Y02
Screen U/F Pump
DRY
TAILS
21-PB-3Y08
Screw O/F
Pumpbox
21-G-3Y08
Screw O/F Pump
O/F
21-TK-3Y05
RCW Tank
Drain
21-VP-3Y02 &
21-VP-3Y04
Polymer Skid & Tank
21-G-3Y10
Polymer Pump
21-G-3Y03
RCW Pump
COLD
WATER
Gland Water
Distribution
Floc Water
21-TK-3Y04
Froth Tank
21-FTC-3Y01
Flot Cell 1
21-FTC-3Y02
Flot Cell 2
21-TH-3Y01
Thickener
FROTH
(to SPP3)
21-TK-3Y03
Flash Flotation
21-G-3Y09
Froth Pump
21-G-3Y07
Froth Pump
21-G-3Y06
Flash Flotation Pump
21-G-3Y05
FTC1 U/F Pump
21-G-3Y04
FTC2 U/F Pump
21-SPI-3Y01/2/3/4
Centrifuges
Bypass
Bypass
From
Screws
Belt Filter
Sump Return
21-PB-3Y01
Cyclone
O/F
Pump
Box
U/F
O/F
HPW to
Belt Filter
ClothWash
21-G-3Y17
Froth Pump
21-G-3Y01
Cyclone O/F Pump
21-VP-3Y14
Belt Filter
Drain
IPEP 500
Phase 3/3B
Streams and Sample Points

Appendix C - IPEP 500 Phase 3B Design Mass Balance

Stream Tables - IPEP 500 Phase 3/3B Design Mass Balance - Fall Average Grade

Stream Number	1	3	4	6	7	8	10	11	12	14	16	18	19
Description	Ore Feed	Crusher HPW dilution	Crusher UF	Coarse Screw OF to FF	Coarse Screw UF to Fine Screw	Coarse Screw RCW	Fine Screw OF to FF	Fine Screw UF to Screen	Fine Screw RCW	Screen UF	Screen UF RCW	Froth	FF UF to FTC1
Total Mass Flow, t/h	500.0	213.4	723.4	206.5	546.9	30.0	416.0	493.5	200.0	152.6	10.0	87.1	612.9
Bitumen, wt%	10.0%	0%	6.9%	8.5%	6.0%	0.5%	7.7%	1.1%	0.5%	2.6%	0.5%	55.0%	2.0%
Water, wt%	4.5%	99.8%	33.9%	66.6%	25.1%	98.9%	71.5%	32.4%	98.9%	73.4%	98.9%	35.0%	76.0%
Total Mineral, wt%	85.5%	0.2%	59.2%	24.9%	68.9%	0.6%	20.9%	66.4%	0.6%	24.0%	0.6%	10.0%	22.0%

Stream Number	21	22	24	25	26	27	29	30	31	32	33	34	40
Description	FTC1 OF to FF	FTC1 UF to Cyclones	FTC2 OF to FF	FTC2 UF to Floc Add'n	Floc	Thickener Feed	Centrifuge Cake	Centrate	Total RCW Required	RCW Drain	Screen UF TK Disch	Screen OF	Crusher Dilution RCW
Total Mass Flow, t/h	28.8	622.0	22.7	476.9	8.4	485.3	32.1	117.9	250.0	228.1	162.6	340.9	10.0
Bitumen, wt%	25.0%	0.8%	10.0%	0.5%	0%	0.5%	0.1%	0%	0.5%	0.0%	2.5%	0.5%	0.5%
Water, wt%	60.0%	78.1%	86.0%	93.9%	100.0%	94.0%	24.9%	99.0%	98.9%	99.5%	75.0%	14.1%	98.9%
Total Mineral, wt%	15.0%	21.2%	4.0%	5.6%	0.0%	5.5%	75.0%	1.0%	0.6%	0.5%	22.6%	85.4%	0.6%

Stream Number	50	51	54	55	58	60	61	64	65	66	67	76	77
Description	Total Tailings	RCW TK OF	Cyclones UF	Cyclones OF	Filtrate	Belt Filter HPW Cloth Wash	Belt Filter Drain	Belt Filter Cake	Total HPW	Gland Water	Total Cold Water	Thickener UF	Thickener OF
Total Mass Flow, t/h	494.4	26.0	139.3	482.7	16.9	24.6	37.8	121.3	238.0	63.2	71.6	150.0	453.1
Bitumen, wt%	0.4%	3.4%	0.2%	0.9%	0.2%	0.0%	0.0%	0.2%	0%	0%	0%	0%	0.5%
Water, wt%	15.0%	95.8%	24.8%	93.4%	97.0%	99.8%	97.1%	14.9%	99.8%	99.8%	99.8%	83.1%	98.9%
Total Mineral, wt%	84.6%	0.7%	75.0%	5.6%	2.8%	0.2%	84.9%	0.2%	0.2%	0.2%	0.2%	16.9%	0.6%

Appendix D - IPEP 500 Photos

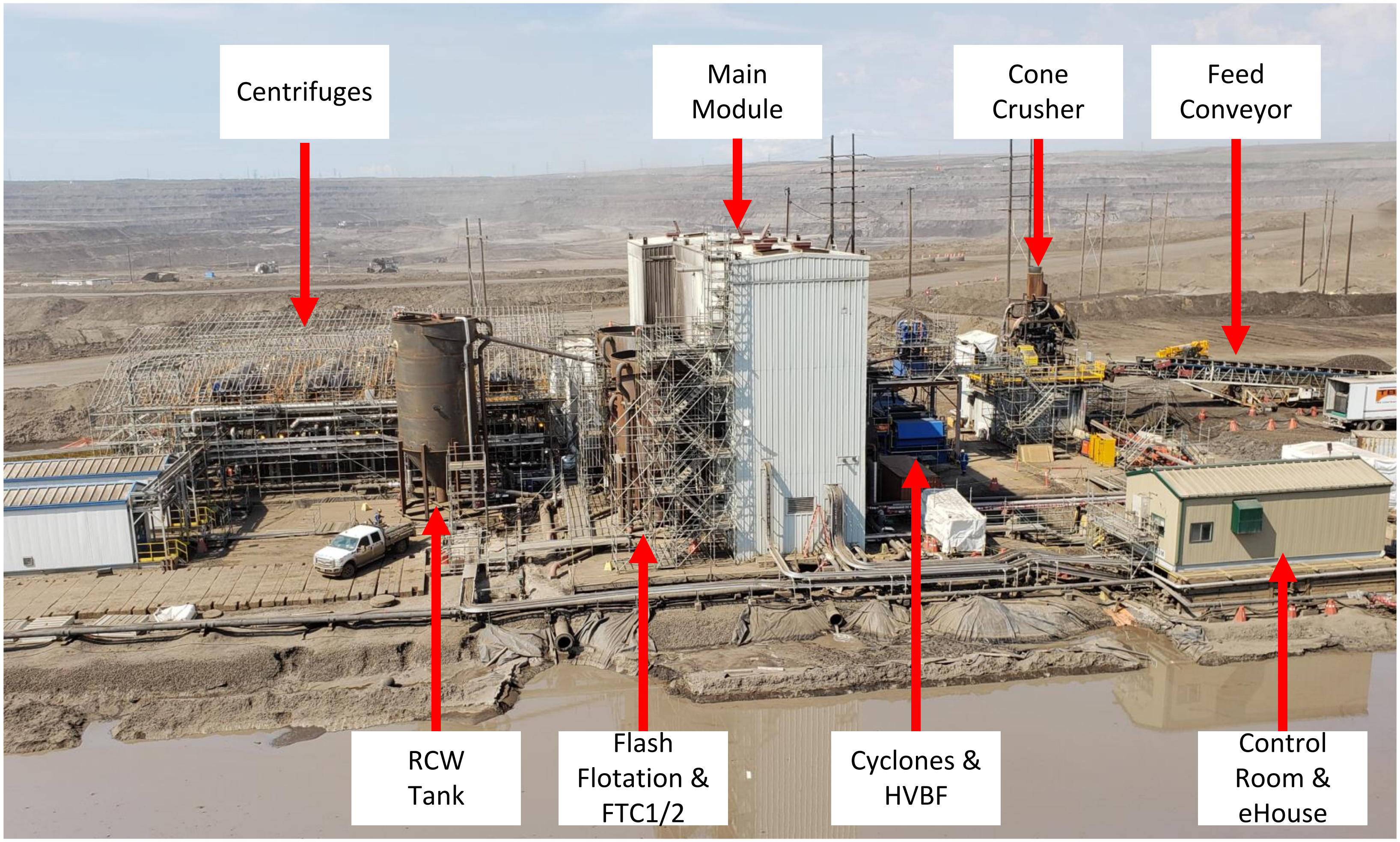


Figure D-1 Overall IPEP 500 (Phase, 3 under construction)

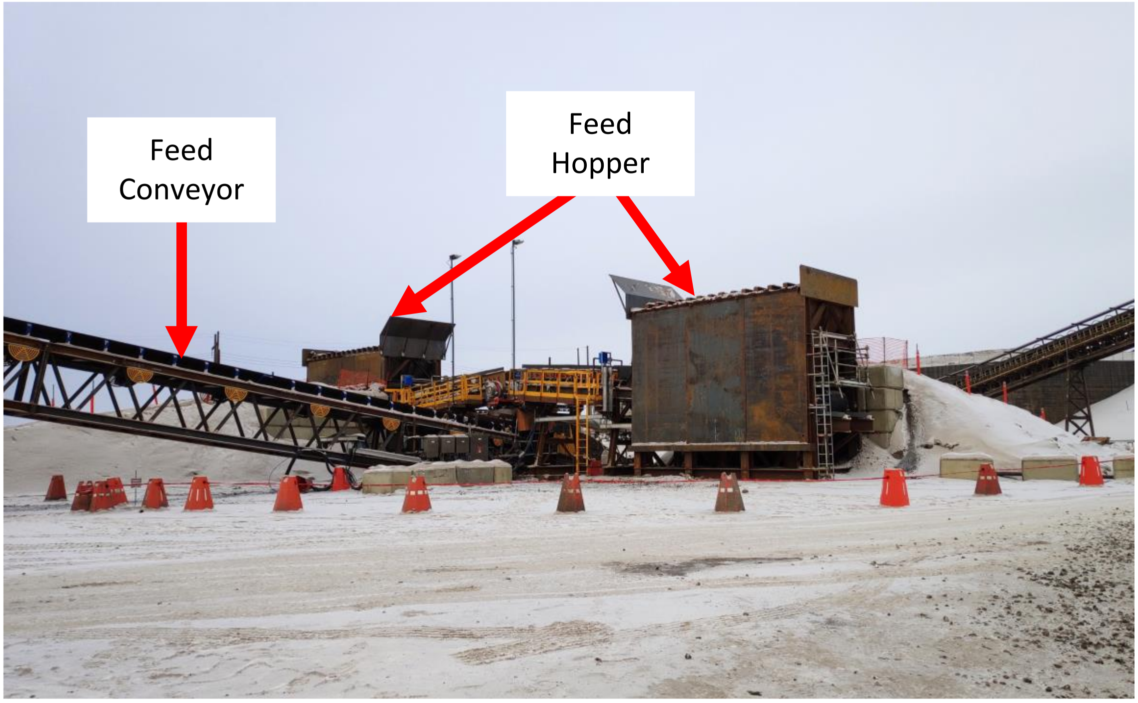


Figure D-2 Ore feed hoppers and conveyors (Phase 3)

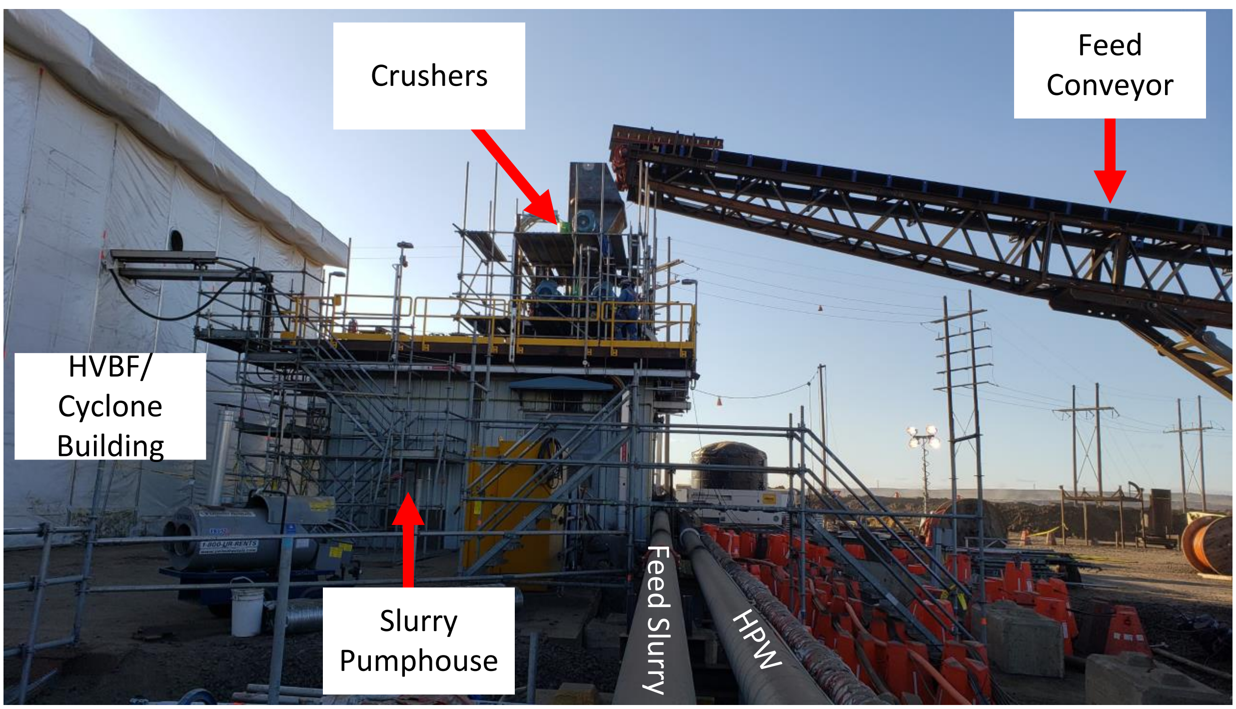


Figure D-3 Ore feed to crushers (Phase 3)

Figure D-4 Cone crusher (Phase 2)

Figure D-5 Crusher teeth (Phase 3)

Figure D-6 Coarse screw washer

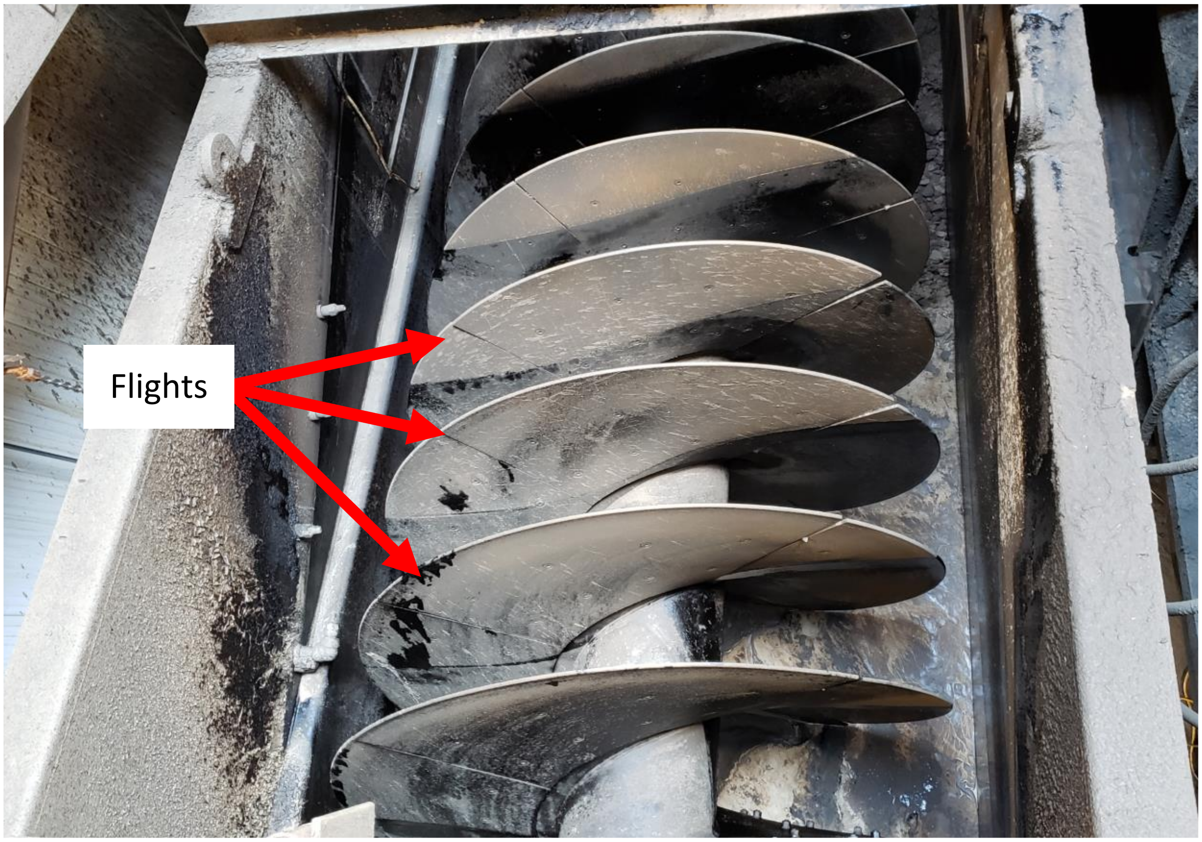


Figure D-7 Coarse screw washer flights

Figure D-8 Vibrating screens

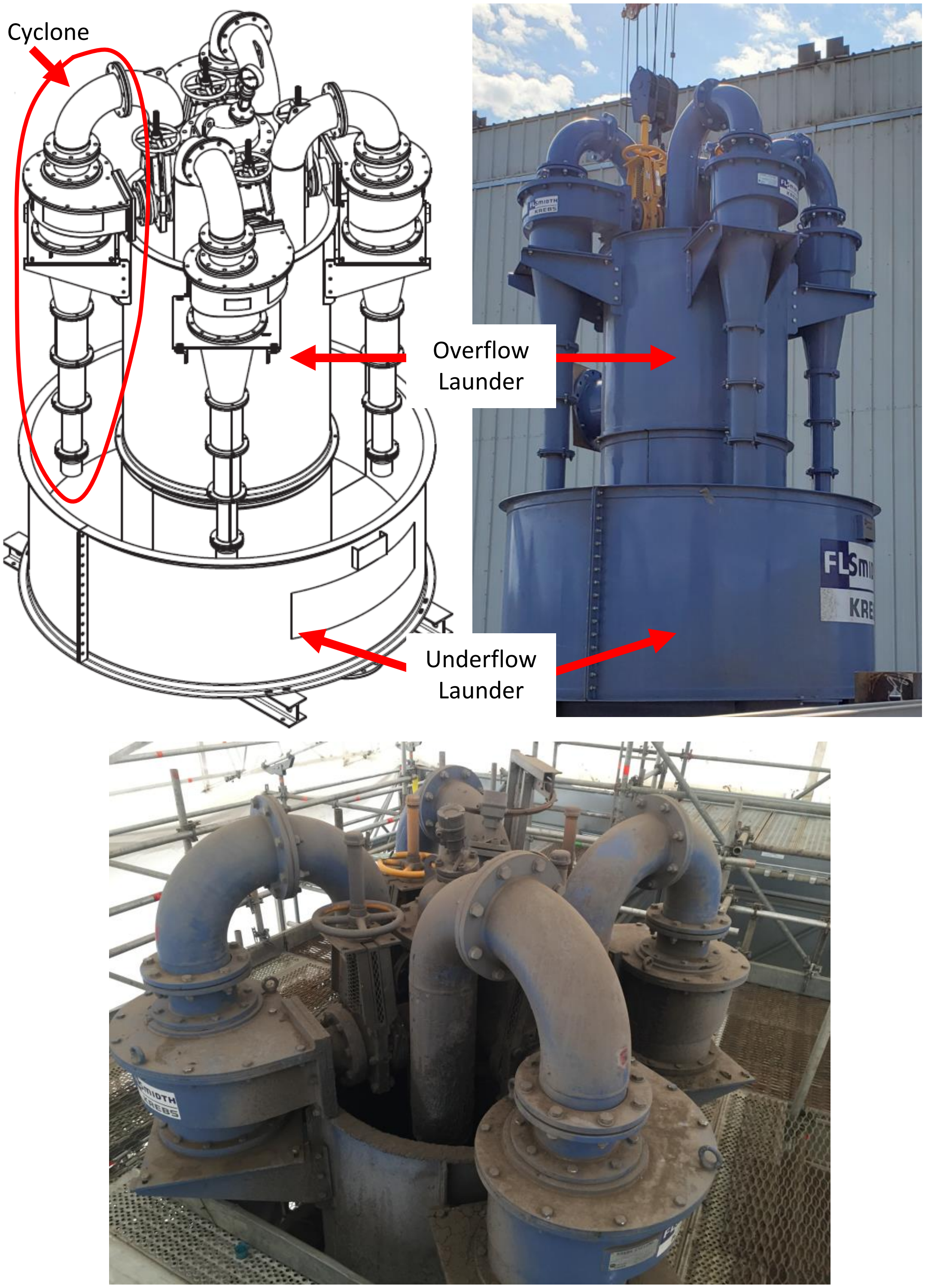


Figure D-9 Cyclopac (Phase 3)

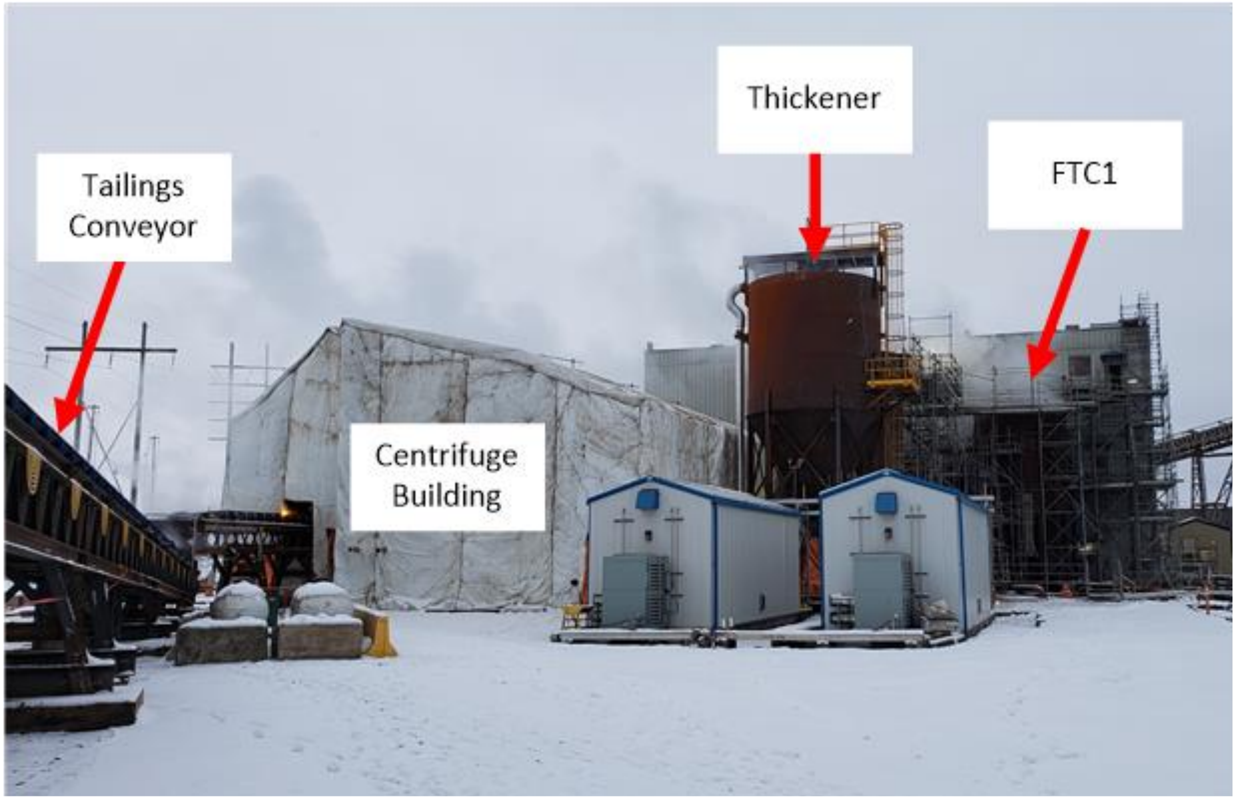


Figure D-10 Centrifuge building (with hoarding), thickener, FTC1, and tailings conveyor

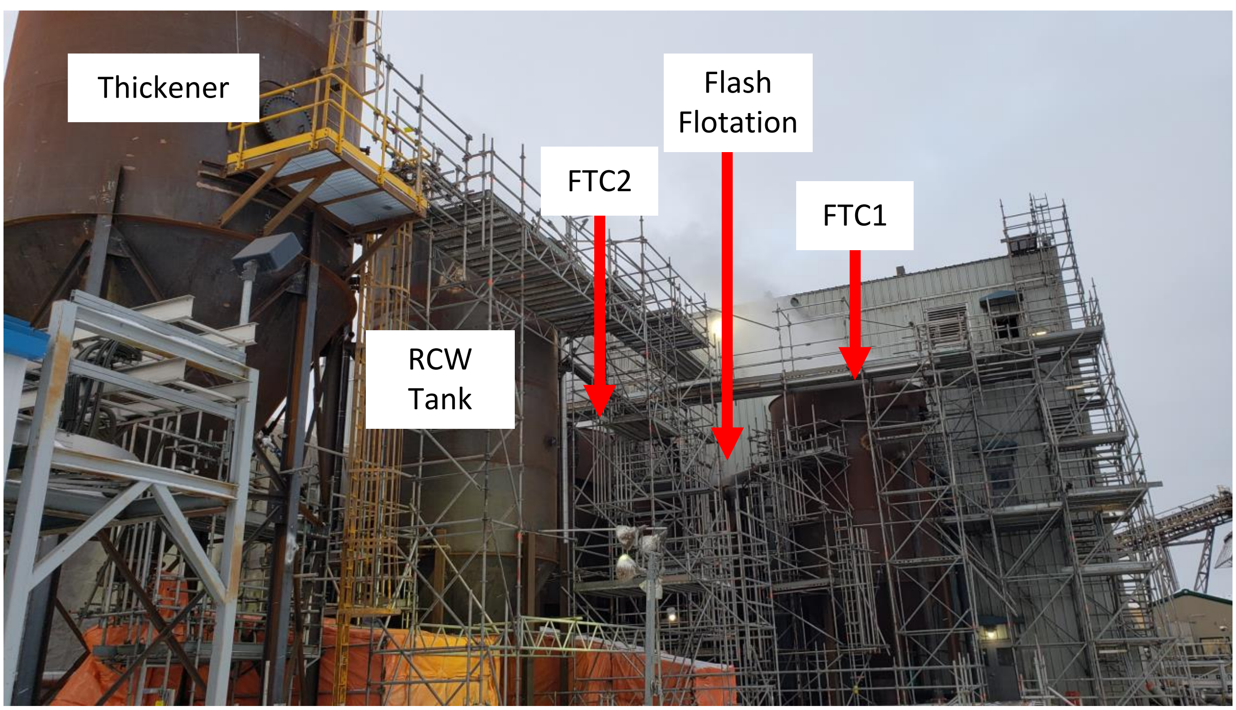


Figure D-11 Thickener, recycle water tank, and flotation circuit (Phase 3B)

Figure D-12 Thickener and recycle water tank (Phase 3B)

Figure D-13 Froth overflow from flash flotation cell

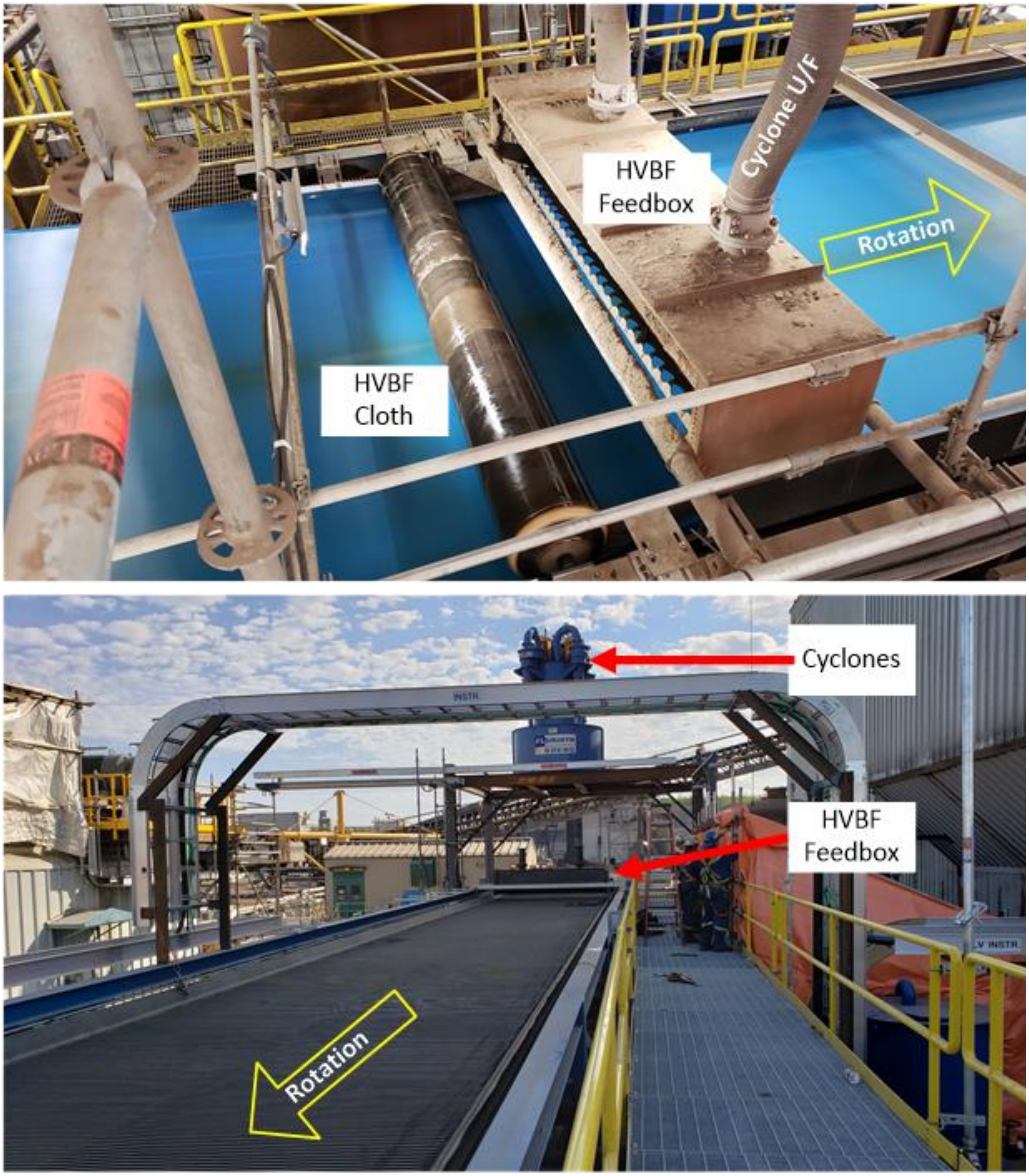


Figure D-14 HVBF installation showing location of cyclopac and HVBF feed box, filter cloth, and direction of travel. (Phase 3B during construction - note filter cloth has not been installed in lower photo and the carrying belt can be seen)

Figure D-15 Belt filter cake falling from cloth at discharge to a tailings conveyor (not shown) (Phase 3)

Figure D-16 Centrifuges and FTC1 during operation (Phase 1)

Figure D-17 Stackable tailings